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Collective C2 in Multinational Civil-Military Operation

An Agent-based Model Simulation of Multiple Collaborating Mobile Ad Hoc Networks (MANET)

Topics: (1) C2 Concepts, Theory, and Policy (5) Collaborative, Shared, and Decision Making, (7) Modeling and Simulation, (9) Networks and Networking

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14. ABSTRACT
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An Agent-based Model Simulation of Multiple Collaborating Mobile Ad Hoc Networks (MANET)

Abstract

The paper presents a preliminary result of using cognitive- and behavior-based modeling framework to simulate a network of MANETs (Mobile Adhoc NETworks) as intelligent agents in a tactical battlefield. We demonstrate the efficacies of an agent-based modeling and the need for developing formal methods for multi-agent simulations from a system of systems (SoS) perspective. The development of our model framework informs the need to describe behaviors and relationships of actors and objects in the context of a mission space, and 2) to provide a foundation for modeling agent behaviors in a way that is plausible with respect to human behavior, a specially from the standpoint of human-system interactions.

1.0. <u>Introduction</u>

The surge in the human dependency on Mobile Ad hoc NETworks (MANET) in various task scenarios (battlefield, emergency response, social network, etc.) is growing exponentially. For example, modern battle command is populated with network-centric physical assets; predominant among these are constellations of MANETs that are used to aid tactical, collaborative communications during real-time battlefield operations. MANETs represent a class of battlefield tactical communication networks that are highly mobile and adaptive with respect to applications. MANETs support robust and efficient battlefield operations, routing, communicating, and distributing information functionalities across their mobile nodes.

Stations in MANETs are usually laptops, Personal digital Assistants (PDAs) or mobile phones. These devices feature Bluetooth and/or IEEE 802.11 (WiFi) network interfaces and communicate in a decentralized manner. Mobility is a key feature of MANETs. Because of their high cost and the lack of flexibility of such networks, experimentation is mostly achieved through simulation.

In the operational environment, MANETs are vulnerable to enemy attacks, failures caused by engineering devices, and occasional degradation due to technology. All these factors require that some enabling tools be developed to support an effective fielding of MANETs for command and control (C2) purposes. It also requires that engineering analysis be conducted to monitor performance over time. Metrics of performance may include vulnerability, resiliency, reliability, trust between users, trust in MANETs, and so on.

MANETs constitute a special class of networks that embrace humans and machines, leading to what may be described as cognitive socio-technical systems (CSTS). This increases the complexities involved how interactions occur in systems: human-human, human-machine, or machine-machines. These qualities demand that MANETs be designed to acquire certain human traits similar to how human interact and behave in dynamic task situations. This is the motivating factor for considering agent models for MANETs. This consideration forces us to look at important human traits such as perception, cognition, behavior, collaboration, and team work. Our agent-based simulation model incorporates these characteristics.

2. Intelligent Agents

Consider a simplified battlefield tactical communication networks shown in Figure 1. We may need to know how agents perceive the environment based on MANET information load (voice, data, voice + data); how humans make decision based on the tactical requirements and supported by MANET; how multiple humans and multiple MANET users interact; and how such interactions enable performance. Answers to these perceptual, cognitive, social, and behavior questions lead to our interest in embodied definitions of specialized cognitive agents for human-mobile network interaction. It is possible to discover new behaviors as a result of many interacting agent behaviors.

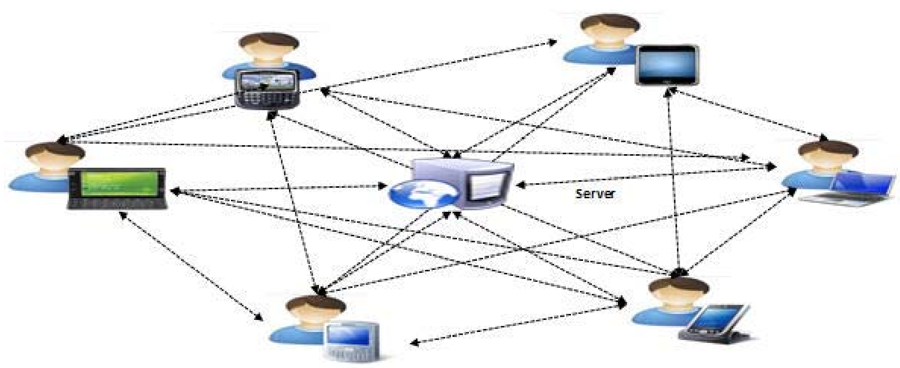


Figure 1. A simplified MANET topology.

Intelligent agents can then be defined as a human or a MANET device that can recognize its environment information, make sense of the context, perform plausible reasoning, and decide on courses of action while collaborating with other agents. In the battlefield environment, the agents should be able to predict the enemy states and plan courses of action to minimize the MANET vulnerability during operations. In concert with these assertions, our agent concept is to develop methods for understanding how MANET operators exploit information in opportunistic domains with adaptive and dynamic windows of decision opportunities; study how agent interactions between MANET and humans, human and human, or MANET to MANET nodes, orchestrate coping strategies during unexpected attacks, uncertainties, information sharing, and how they collaborate to redefine new goals during system agitation states. Table 1 gives an anectodal view of some of the methods for collaboration by agents.

Table 1: Possible agent collaboration modalities

	MANET device	Human
MANET device	Instructions and rules	Model-based predictions and look-up table
Human	User-interface, visual tools	Social-based: dialogs and communication

Drawing from many definitions and requirement studies in the agent community (Wooldridge, 1995), SoS (Wegner, et al., 2006), M&S (Bernstein, et al., 2006) ,social sciences and cognitive psychology, an intelligent is likely to possess at least one of the following properties:
(1) Emergence –the notion that the interaction of technological, cognitive, social, and ecological systems will give rise to a collective pattern of behaviors that differs remarkably from the presumed behaviors from each of sub-systems;
(2) Dynamic- the notion that behavior change is situated in time and space given rise to temporal and spatial behaviors, respectively;
(3) Spiral model—the notion that due to interaction of multiple behaviors, the resultant system behaviors are non-linear and understanding information flow and their functions is through a continuous spiral feedback model;
(4) Self-organized—the notion that agents that have intelligent can adapt and re-organize their behaviors for planning during contingencies;
(5) Distributed cognition—the notion that each agent in the system share the same goal and seamlessly distribute what they know with each other;
(6). Sensemaking—the notion that agents can reduce equivocal information to a common metric for use in an intended goal execution, and collectively seek prospective information for coping with future state changes (Ntuen, 2006);
(7). Agitative states—the notion that MANET agents in the battlefield operate under stress levels which have the effect of diminishing the full functioning of the agent's performance such as reduction of awareness and attention.

Intelligent agents must be able to learn (through various methods such as reinforcement, Bayesian, feedback, imitation, etc). They must exhibit certain levels of expertise based on level of assigned experience on a task, demonstrate intelligent or ignorance of a subject matter, and be vulnerable to intentional bias (Kahneman, Slovic, and Tversky, 1999). Premised on these human-like characteristics, a MANET node is considered to represent an agent of human and device entities. Thus a node can exhibit behaviors of various forms—from passive to active, static to adaptive, and be capable of demonstrating selfish-, collaborative-, and participative-, leadership-, and followership-behaviors. A learning agent is also constructed to have situation awareness capability while interacting with its environment. Hence, an agent can monitor the behavior of other agents, take commands from a command and control (C2) agent, understand its roles and when to perform them, learn personal and organization level preferences, and be able to predict future actions. The objective of this work is to incorporate these capabilities to the MANET agents

3. A Cognitive Model of MANET Agents

The core technical challenge of our work involves tackling cross-disciplinary issues of dynamic network protocol and multi-agent system design. An obvious approach is to build an agent out of two (or more) subsystems: a deliberative one, containing a symbolic world model, which develops plans and makes decisions in a rational manner; and a reactive one, which is capable of reacting to events that occur in the environment without engaging in complex reasoning. Often, the reactive component is given some kind of precedence over the deliberative one, so that it can provide a rapid response to important environmental events. Rather than the classical approach of symbolic reasoning, it is assumed here that agent's dynamic behavior is a result of interaction with other agents and the environment in which it works. The agent's ability to reason is not necessarily a sufficient condition for sensemaking, but the resultant behaviors arising from interactions—socially and ecologically.

One novel approach to representing intelligent behaviors to MANET agents is to use the OODA(Observe, Orient, Decide, Act) model. This is shown in Figure 2 for a four-node MANET system. The OODA model was developed by Boyd (1987) to address the concerns of military decision-making processes that consider uncertainties. In the OODA model, the "Orient" sub-model attempts to capture the cognitive processes involved during sensemaking—although it was never addressed as such. The components describe the human cognitive tasks with feedback and feed-forward loops. Boyd describes the sensemaking process in four stages with the orientation stage being the stage at which most of the sensemaking process takes place.

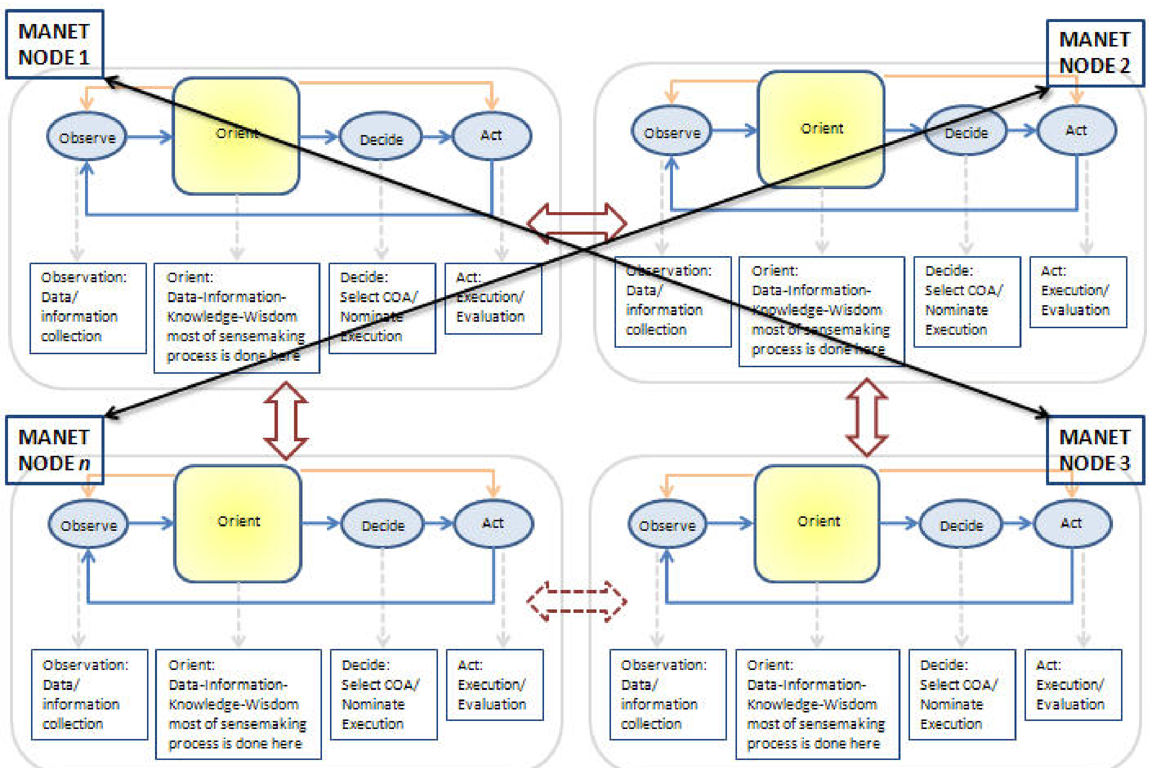


Figure 2. Multiple connected OODA for MANET agents

The multiple connected OODA network is modeled as a propositional network. According to Black [5], propositional networks are sets of entities illustrated by their interrelated relations and properties. It is similar to concept map in that they both represent knowledge structures and contents in a declarative way. The causal relations in concept map can also be represented as a series of condition-action or if-then rules.

The model framework is based on shared ontology. Ontology is often defined as an “explicit specification of a conceptualization” (Fox & Gruninger, 1997; Gruber, 1993). It is used to define and organize knowledge concepts in a system. Thus, ontology can be regarded as a tool for information network management. The ontology approach for the multiple OODA network is simple: *When we perform actions, we do so after a careful selection, often through rational model, of interrelated activities*.

The spatial connection or relationship of nodes (with each node with agent properties) and their intentional forms a network, referred to here as a Knowledge Action Network for Agents (KANA). KANA is a construct similar to Black’s propositional network, except that KANA allows for representation of retrospective, current, and prospective sensemaking schemata for agents so as to enable reflexive and envisioning reasoning behaviors. KANA also allows representation for agents to collaborate during a reasoning process to manage uncertain system resources to achieve intended system-level actions. KANA is designed to capture and build behavior relations between agents employing well matured cognitive tools such as activity theory, cognitive task analysis, behavior analysis, functional requirement specification, and operation tracing and mapping. For example, social behavior ontology should be able to represent: how interactions occur among agents; how collaborations take place; how agents negotiate and reach consensus; and how leaders are selected among agents. A more global ontology may represent how variability in agent behaviors are captured over time (temporal), space (spatial), location of activity (situational), and effect of workload (conditional). KANA also addresses human dimensions, conditions and rules for behavior representations, autonomy, and intention (shared and individual), and characteristics of SoS at different platforms and design hierarchies (e.g., soldier, tank, platoon, etc.) as explicated on the battlefield (Cioppa, Lucas, & Sanchez, 2004).

We consider MANET agents to learn and understand the human user actions. These agents should be able to **P**redict, **E**nvision, **A**nticipate, **R**eason, and **L**earn (PEARL). This leads to the concept of **PEARL** as a high-level meta-agent for supervising the behaviors of other agents. They can use what they have learned from interactions to determine what to do in the future within its environment. The learning agent watches out for themselves, enforcing their own individual preferences and taking advantages of others preferences and biases. PEARL has a three-stage interacting layer: a currency layer which has some or all information about the current state of the system; a retrospective sensemaking layer which has some or all the pertinent information about the past system behaviors and performance measures, including, e.g, beliefs either about the external world or the system’s internal state; and prospective (envisioning) state which has models of a system and its agent behaviors. The success of PEARL lies on how information is shared between agents. Thus, PEARL allows agents the ability for perceptual-control of dynamic actions through learning, shifting system goals, time pressure, information dynamics, complex battlefield operations requiring adaptive courses of actions, skill acquisition, adaptive and self-organizing behaviors, visualizing problem space, and hierarchical multilayer interaction of command and control tasks between and among agents (human and software) performing tasks, sharing resources, and self organizing--including exchanging leadership roles in the cell—such as switching roles and building redundancy systems (self-satisficing solutions) during high workload in the SoS; and autopoiesis--a self-production - maintenance of a living organism's form with time and flows.

4. SAMPLE SIMULATION

We are developing two agent-based environments. The first is a constructive simulation based on network and graph theory. Here the user can create arbitrary number of MANET nodes and conduct the simulation experiment over a stipulated use time. This is shown in Figure 3a. For each node, the user assigns the agent roles such as scouting, security operation, etc., node potential failure mechanisms, a list of potential vulnerable factors (e.g., jamming, disruption, spoofing, attack, fake routing message, interceptions, etc.) and the risk factors for each events. The collection of agent properties is shown in Figure 3b. The simulation can produce statistics as queried by the user. For example, in Figure 4, statistics on C2 manager (from PEARL agent) is produced. In Figure 4 PEARL agent can produce situation watch statistics such the net intrusion (89.3%), device failures (33.8%), communication failure (85.5%), and discrepancy in messages (38.8%). PEARL also identifies enemy spying into the network (91%), listening to communication (20%), and attempted attacks on the network (61%). PEARL agent uses cause-effect and pattern mapping to predict the network behaviors. For instance, the simulation showed that loss of information was detected 30.3%, information degraded about 73.7%, and there were critical changes in node behaviors (83.7%). The consequences for these actions are identified. For instance, loss of safety occurred 73% of the time these events happen. The vulnerability of the network in this example is 66.8%--meaning that the network is vulnerable to outside incursions or likely to fail in performing its duty 66.8 percent of the time.

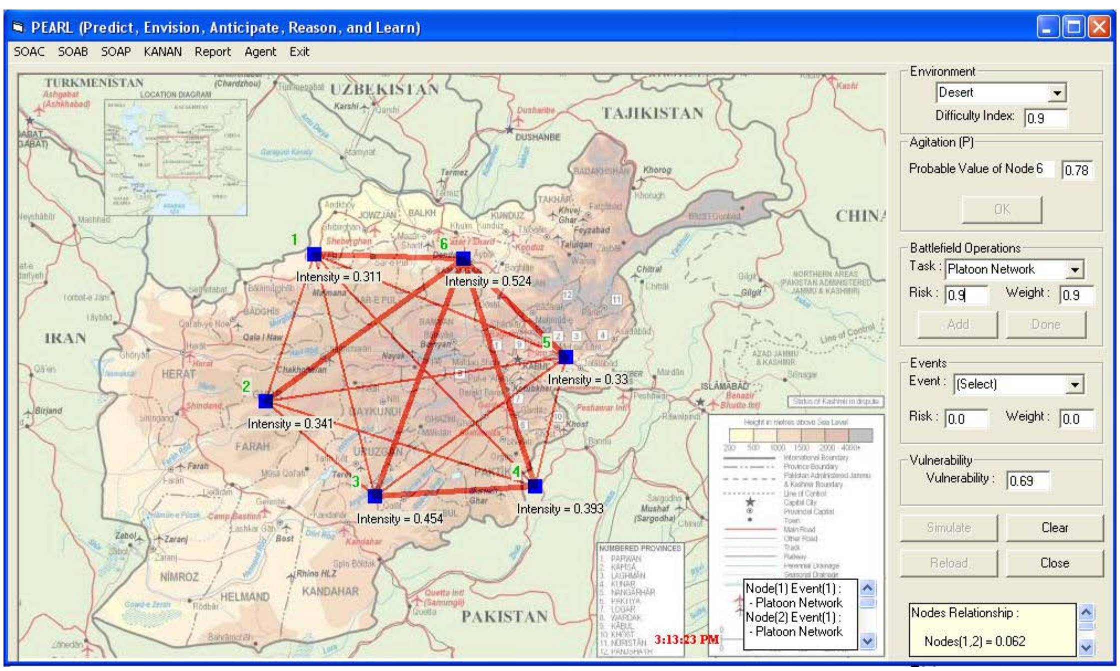


Figure 3a. Sample MANET nodes

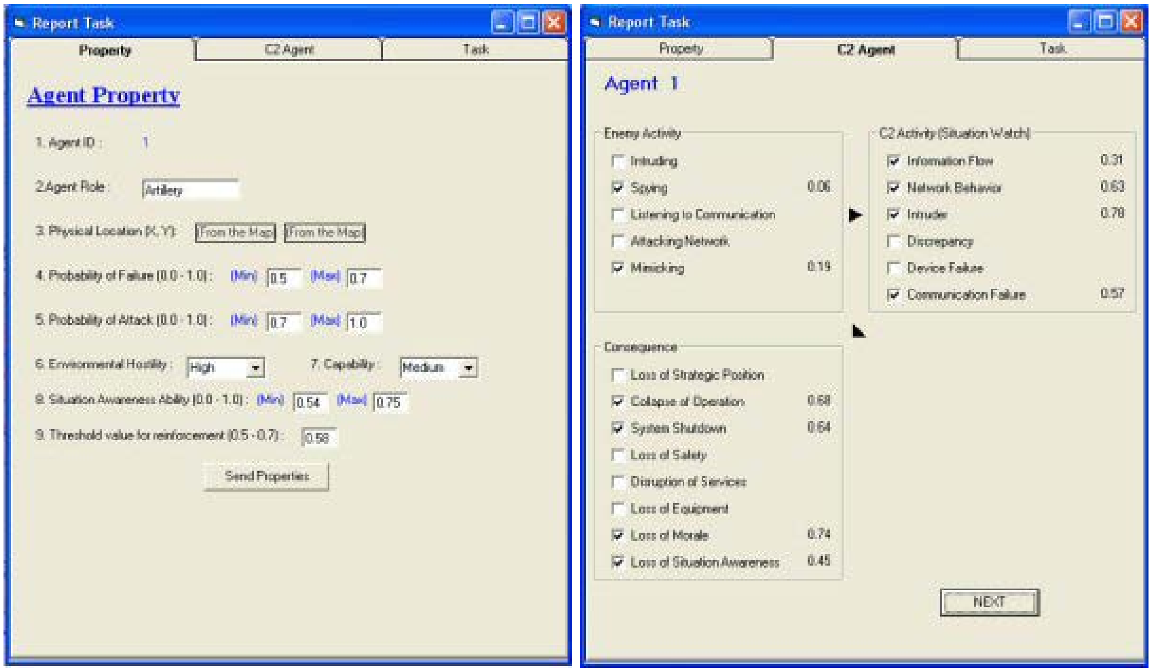


Figure 3b. A window to capture agent properties

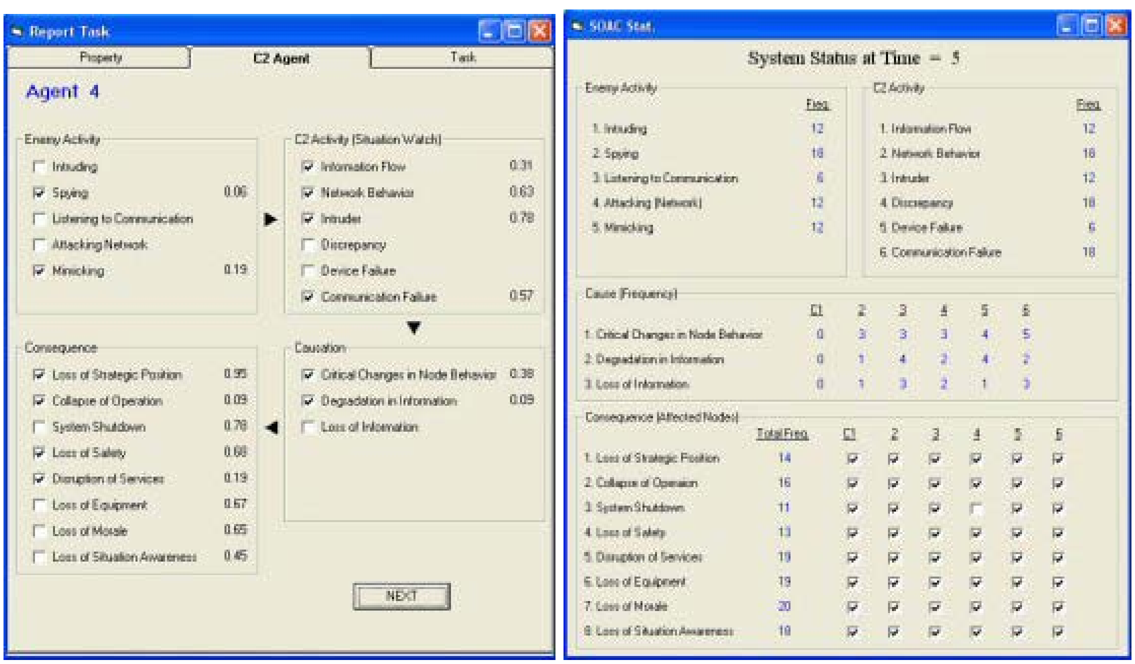
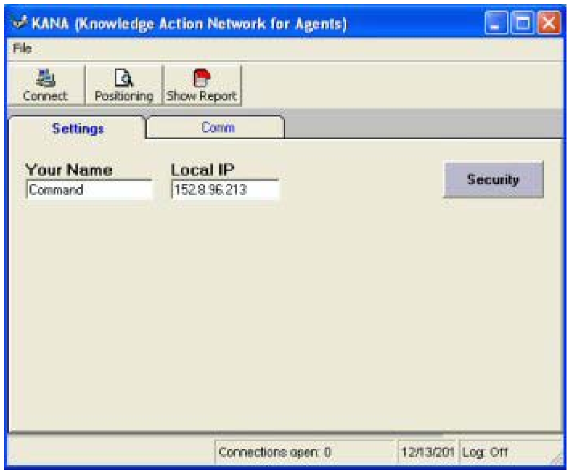
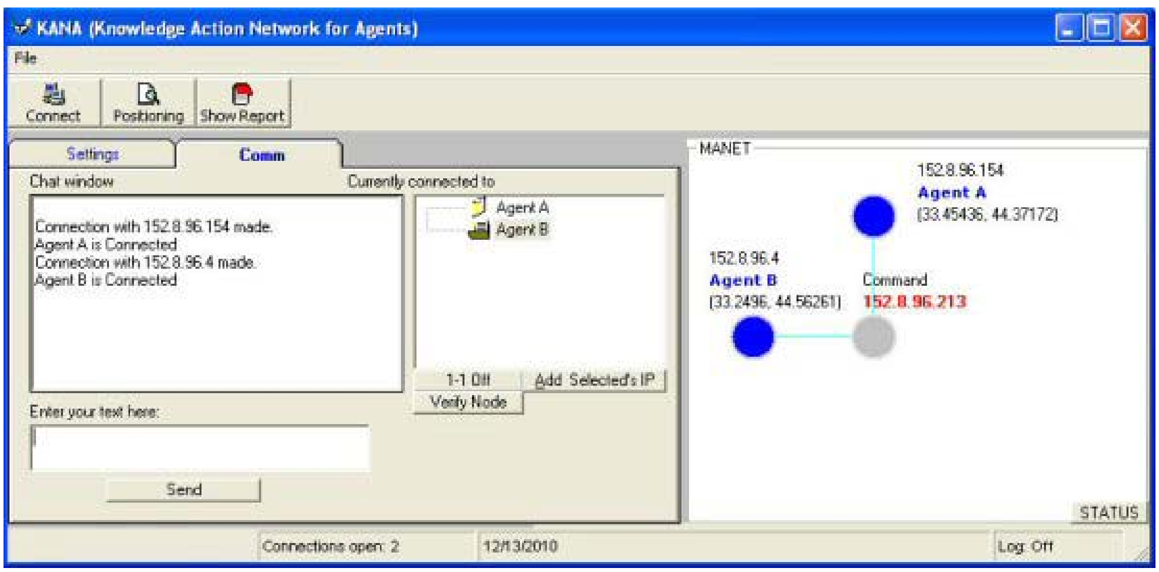


Figure 4. Sample output statistics from PEARL agent

4. Performance Evaluation of a Battlefield Visualization Tool

The second part of the project is the experimental domain which seeks to mimic MANET behaviors using a collaborative sensemaking software system (S3) developed by Ntuen, Park, and Kim (2008). Here, we allow up to three users and computers that are remotely (geographically dispersed) within our laboratory to serve as different MANET nodes. The purpose of this is to enable real-time technology transfer. At the present time, Figure 5 shows and example experimental simulation for direct and active MANET configuration. In Figure 5, two MANET nodes (users) and C2 (PEARL) are configured as shown on the upper part of the Figure 5. The lower part of Figure 5 shows sample window that captures agent (Node) information in real-time information. Figure 6 shows an example of how PEAR recognizes intruder by asking for node entry verification.





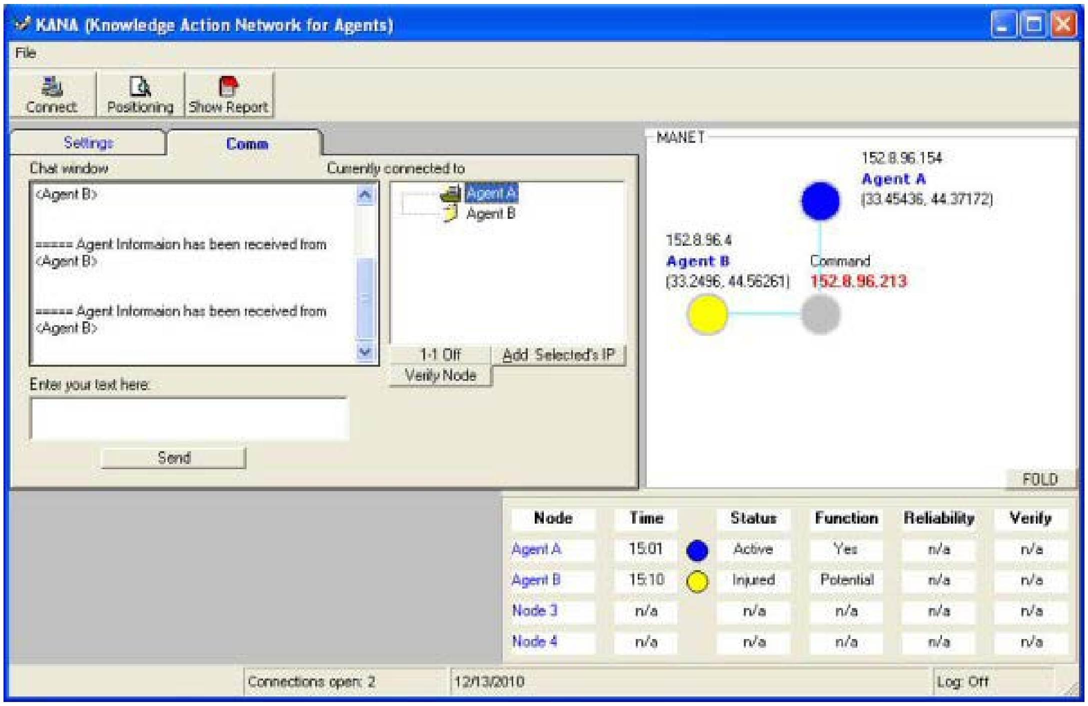
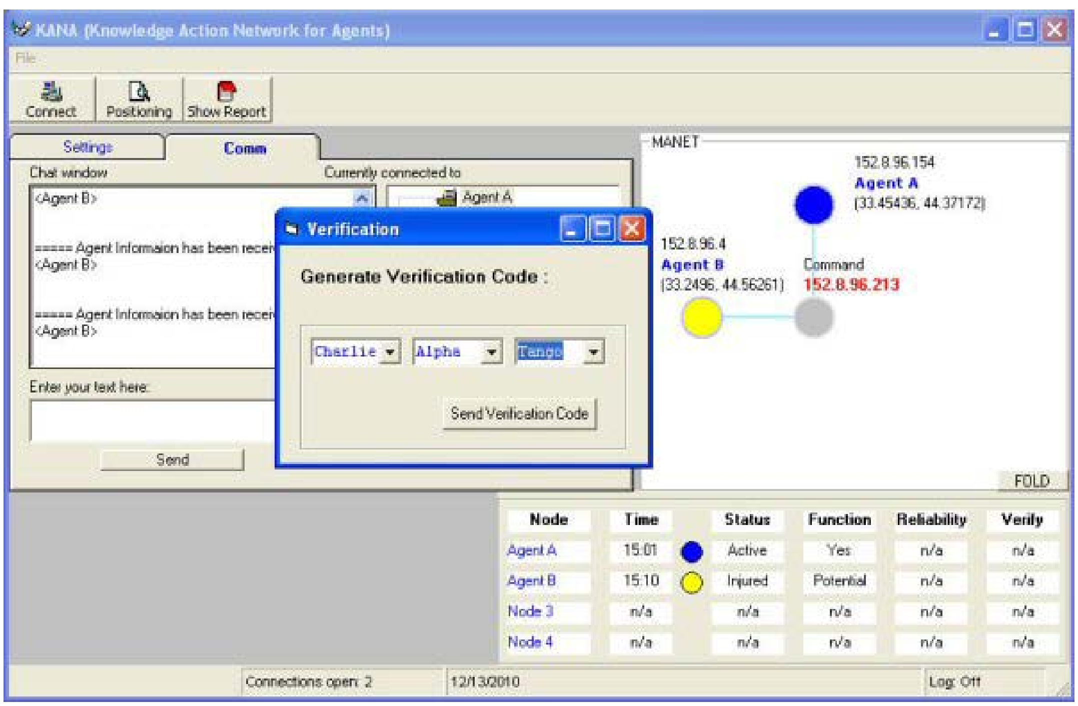


Figure 5. Sample MANET agent experimental frame.



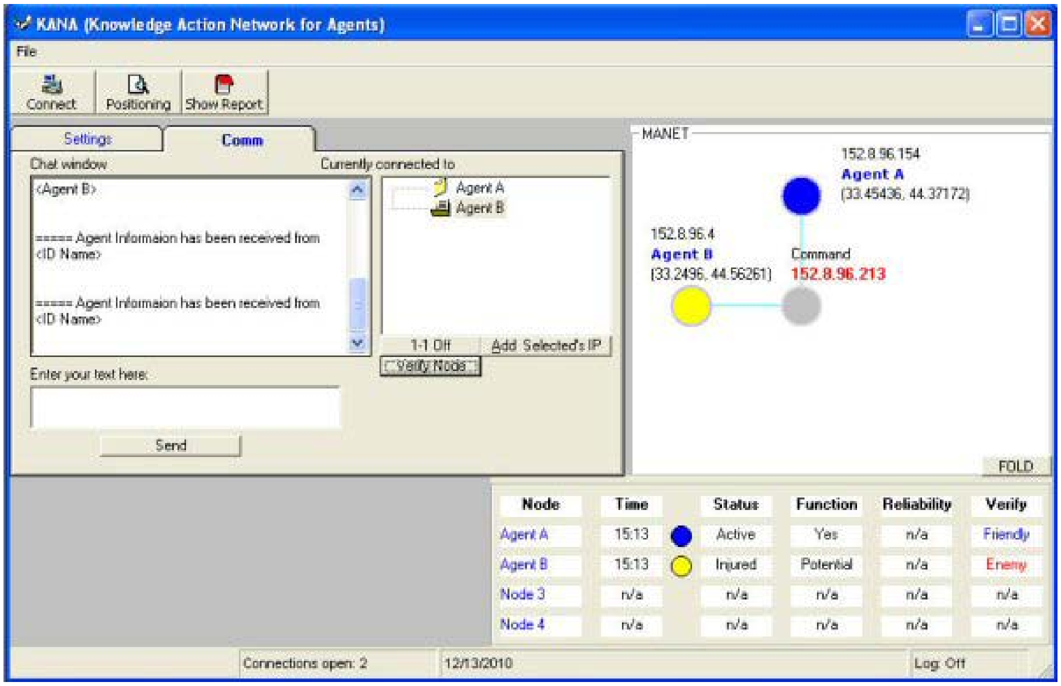


Figure 6. Network intrusion detection and verification by PEARL agent

4. Summary and Conclusion

MANETs constitute a special class of networks that embrace humans and machines, leading to what may be described as cognitive socio-technical systems (CSTS). This increases the complexities involved how interactions occur in systems: human-human, human-machine, or machine-machines. Modeling MANET from the standpoint of system of systems is the focus of our on-going project. The current results are anecdotal with respect to scale-down properties scoped for demonstration of the efficacy of agents in a system of systems (SoS) MANETs. From our pilot study, two fundamental meta problems are constraints to realistic cognitive modeling and representation of agent properties. The first is dealing with adaptive behaviors as a consequent of information changes from battlefield tasks and the supporting mobile wireless communication networks. KANA knowledge manager in our system is designed to manage this kind of situation in large-scale complex networks. The second challenge is reducing complicated and complex human observable behaviors to simple qualitative rules for agents to learn. We achieved this by using decoupled OODA models.

In our simplified experiments with PEARL agent, we can compute useful MANET network properties such as vulnerability, resiliency, and reliability. We are not dealing with the typical network statistical characteristics such as centrality. Hence, there are other human-centric agent properties to be added. These include, but are not limited to, how agents believe each other as a function of stereotypical and bias knowledge, social affinity as a function of team situation awareness and collaboration, how agents bind problems in context and provide solutions when faced with uncertainties and surprise, how agents learn (e.g., what important factors make an agent to use, say, reinforcement learning as opposed to imitation learning), the kinds of emerging behaviors when an agent interacts with other agents in context, and the level and probability of self-organization by agents when a network is attacked. These issues are critical to the survivability of MANETS in battlefields.

Our simplified simulation further inform that: (a) if decision making in a dynamic battlefield problem solving environment is to be driven by simulation, it is necessary to develop real-time models than can self organize in response to new information; (b) SoS simulation inherits special properties of advanced distributed simulation which requires rapid information processing and manipulation of extremely large information; and (c) when multiple entity behaviors interact, it is possible to derive latent intelligent behaviors that make the functioning of SoS scalable across different echelons of information abstraction and control. These are the basic research problems our agent-based environment will address as an on-going research.

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AN AGENT-BASED MODEL SIMULATION OF MULTIPLE COLLABORATING MOBILE AD HOC NETWORKS (MANET)

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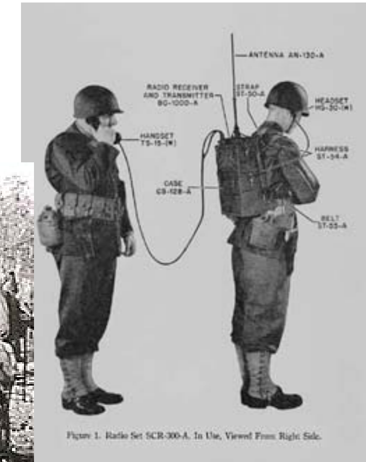
Presentation Outline

1. Background
2. Research Motivation
3. Approach
4. Modeling & Simulation
5. Simulation Results
6. Summary and Conclusions

BACKGROUND

MANET: A popular acronym for Mobile Ad hoc NETwork

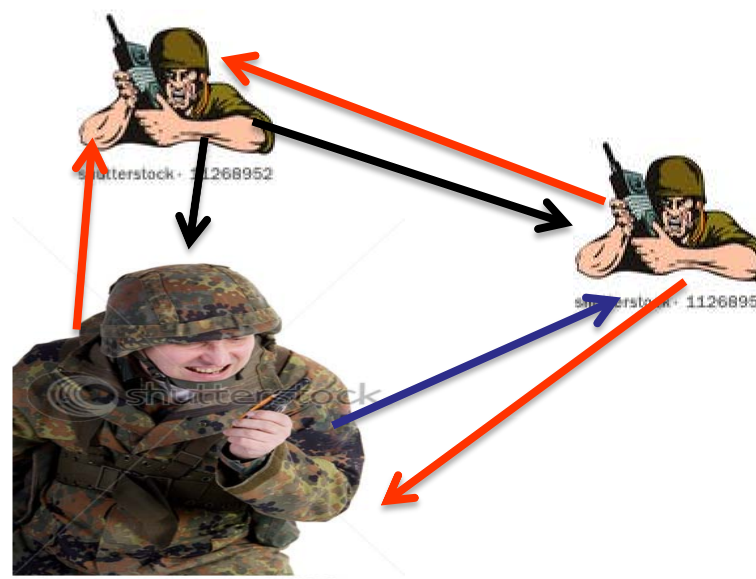


✓A MANET is an autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links.

✓Since the nodes are mobile, the network topology may change rapidly and unpredictably over time.

✓ The network is decentralized, where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves, i.e., routing functionality will be incorporated into mobile nodes.

✓A hybrid of human-machine- or machine-machine- system



BACKGROUND

- Mobile
  - Random and perhaps constantly changing
- Ad-hoc
  - Not engineered
- Networks
  - Elastic data applications which use networks to communicate

Ad hoc networks:

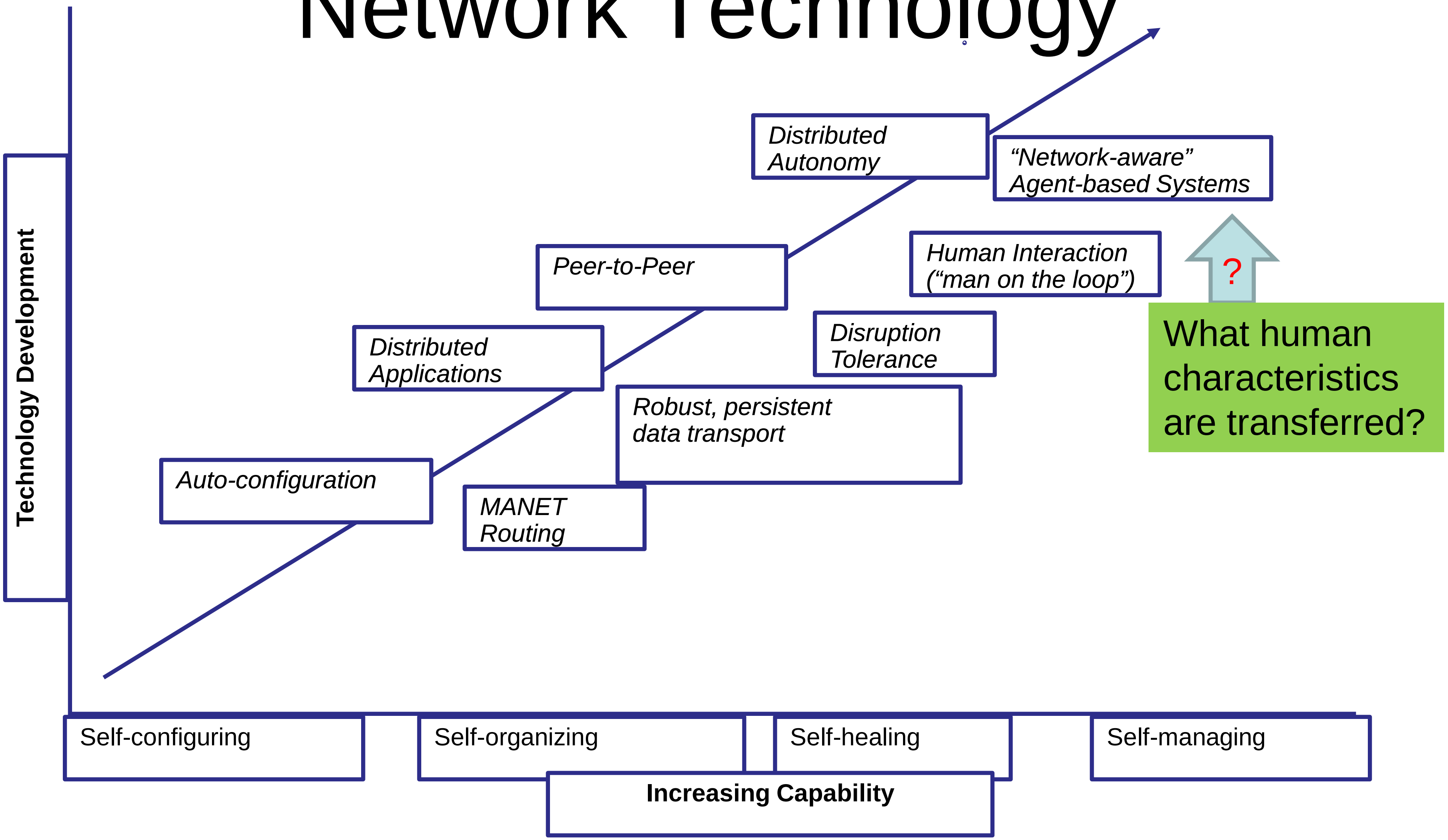
Do not need backbone infrastructure support

Are easy to deploy

Useful when infrastructure is absent, destroyed or impractical

- Interconnected collection of wireless nodes
- Nodes enter and leave over time
- Nodes also act as routers; forward packets
- No pre-established network infrastructure
- No centralized administration
- Communication using BlueTooth and WAP

Envisioned Evolution of Network Technology



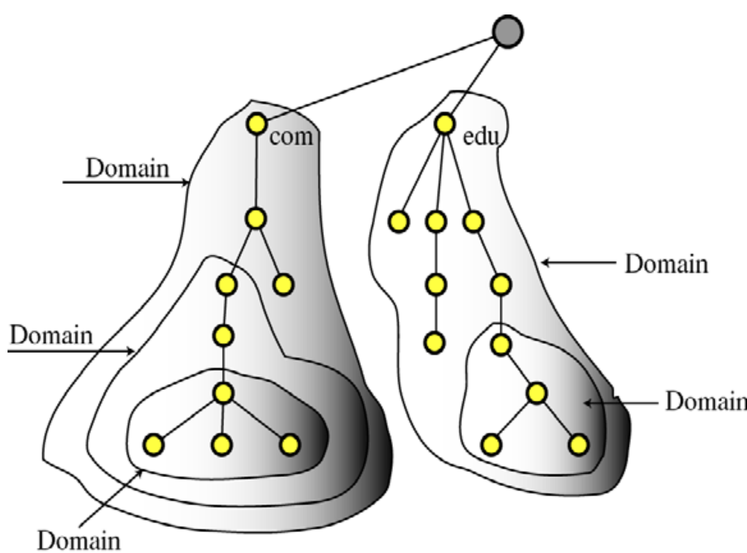
From : Brian Adamson, NRL

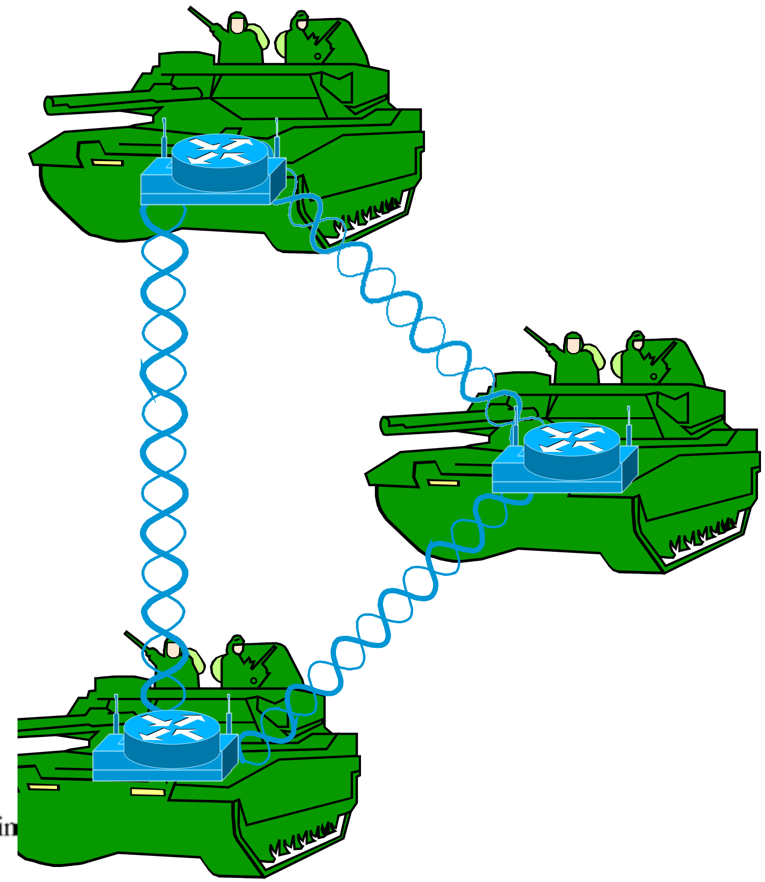
Many Applications of MANET

- Personal area networking
  - cell phone, laptop, ear phone, wrist watch
- Military environments
  - soldiers, tanks, planes
- Civilian environments
  - taxi cab network
  - meeting rooms
  - sports stadiums
  - boats, small aircraft
- Emergency operations
  - search-and-rescue
  - policing and fire fighting

Military applications

- Combat regiment in the field
  - Perhaps 4000-8000 objects in constant unpredictable motion…
- Intercommunication of forces
  - Proximity, function, plan of battle
- Special issues
  - Low probability of detection
  - Random association and topology





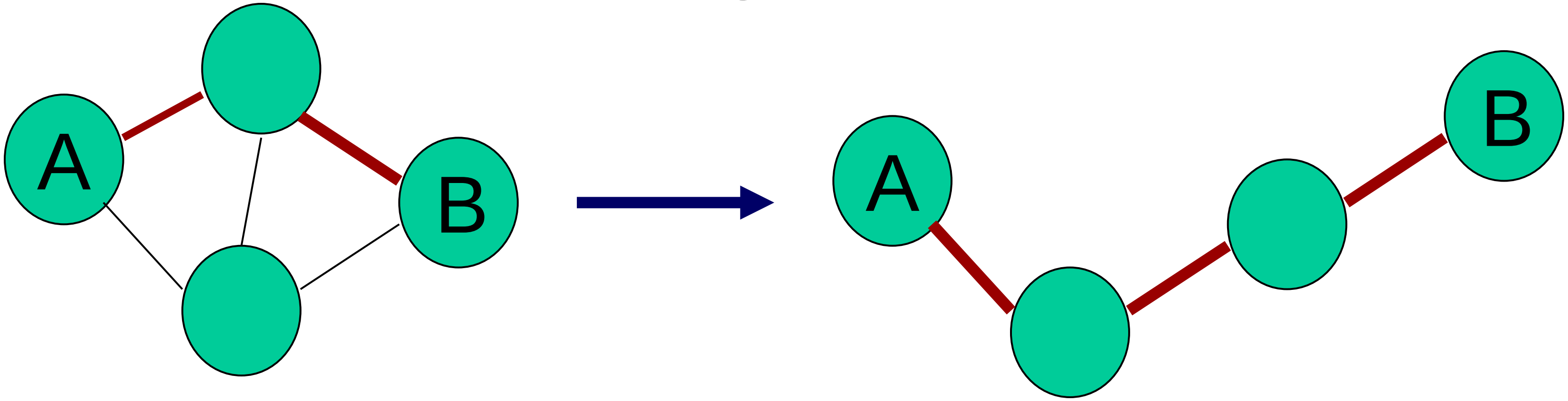
Challenges in Mobile Environments

- Limitations of the Wireless Network
  - packet loss due to transmission errors
  - variable capacity links
  - frequent disconnections/partitions
  - limited communication bandwidth
  - Broadcast nature of the communications

- Limitations Imposed by Mobility
  - dynamically changing topologies/routes
  - lack of mobility awareness by system/applications

- Limitations of the Mobile Computer
  - short battery lifetime
  - limited capacities

Challenges Continue



- Dynamic Topologies and node memberships
- Bandwidth constraints
- Many Transmission Errors
- Energy-constrained operation

Community Attention to Manets

- Routing/ packet scheduling
- *Reliability*
- *Lethality*
- *Energy consumption and longevity*
- *Vulnerability*
- *Mobility*
- *Security*
- *Survivability*

Motivation

- MANET as a human-machine system

- MANETOLOGY: Develop a network theory for human-machine system (with MANET = machine)

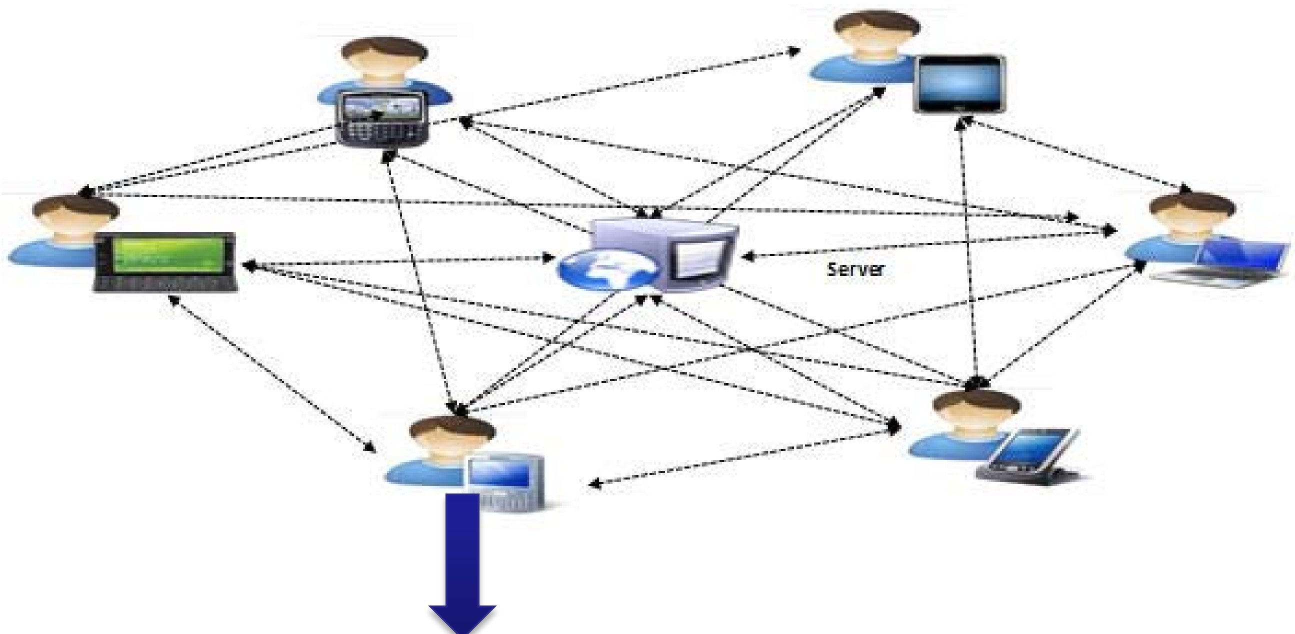
1. Allows for modeling of fundamental human characteristics in intelligent agent-based networks.
2. Allows for representation framework for CSTS
3. Advance cognitive network theory for modeling and simulation

Question: Does agent-based MANET performance (measured by vulnerability) affected by human traits like behavior, perception, and cognition abilities?

INFLUENCING FACTORS FOR MANETOLOGY

(1) Emergence – the notion that the interaction of a technological, cognitive, social, and ecological system will give rise to a collective pattern of behaviors that differ remarkably from the presumed behaviors from each of the sub-systems;
(2) Dynamic – the notion that behavior change is situated in time and space giving rise to temporal and spatial behaviors, respectively;
(3) Spiral model – the notion that due to the interaction of multiple behaviors, resultant system behaviors are non-linear, and understanding information flow and their functions are mediated through a continuous spiral feedback model;
(4) Self-organized – the notion that agents that have intelligence can adapt and re-organize their behaviors for planning during contingencies;
(5) Distributed cognition – the notion that each agent in the system share, the same goal and seamlessly distribute what they know with each other;
(6) Sensemaking – the notion that agents can reduce equivocal information to a common metric for use in an intended goal execution, and collectively seek prospective information for coping with future state changes (Huang & Chang, 2006);
(7) Agitative states – the notion that agents for military M&S will operate under stress levels which have the effect of diminishing the full functioning of the agent’s performance such as reduction of awareness and attention.

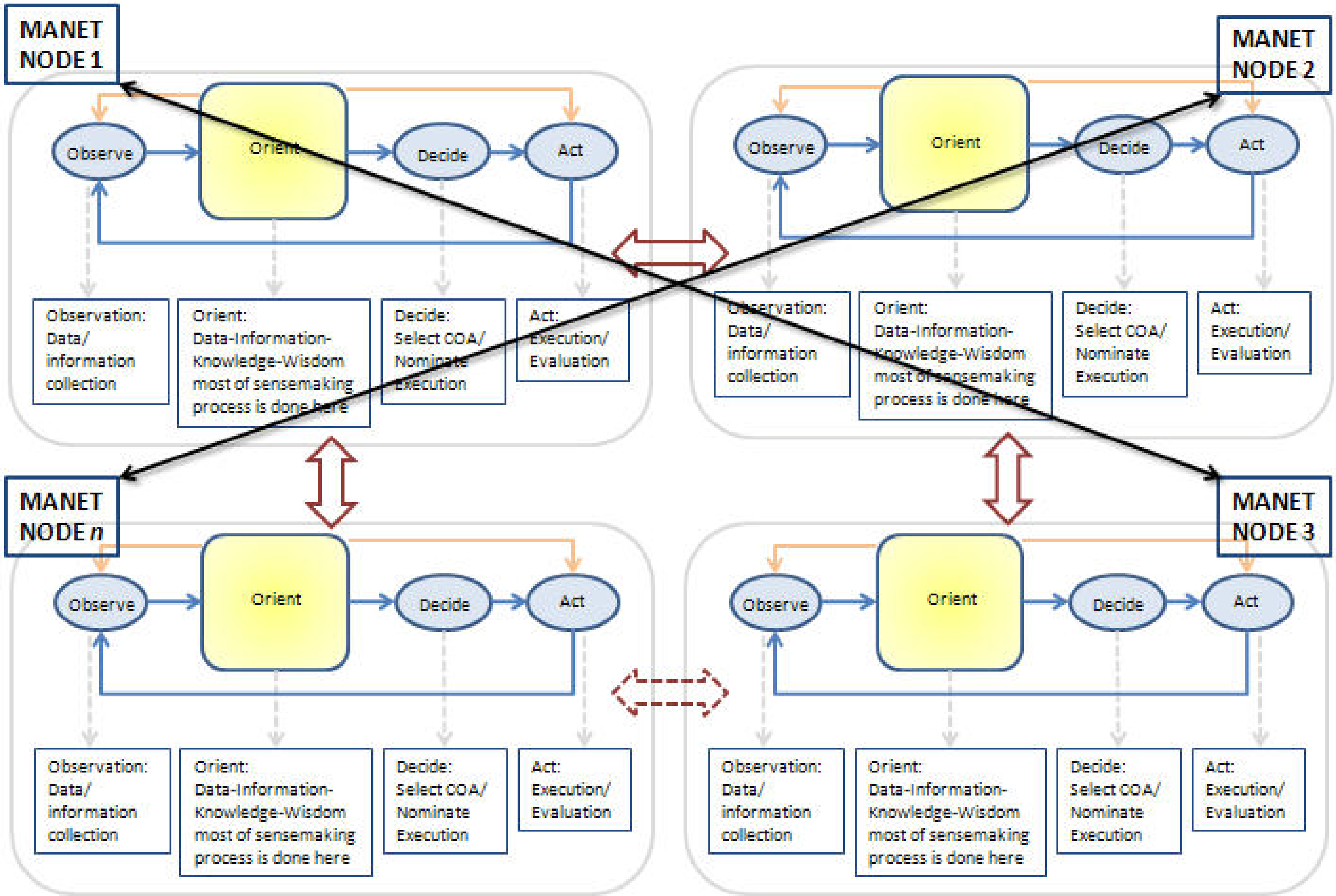
APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS)



At each node, the human activities are to Observe, Orient, Decide, Act

	MANET device	Human
MANET device	Instructions and rules Automated behaviors	Model-based predictions and look-up table
Human	User-interface, visual tools	Social-based: dialogs and communication

APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS)

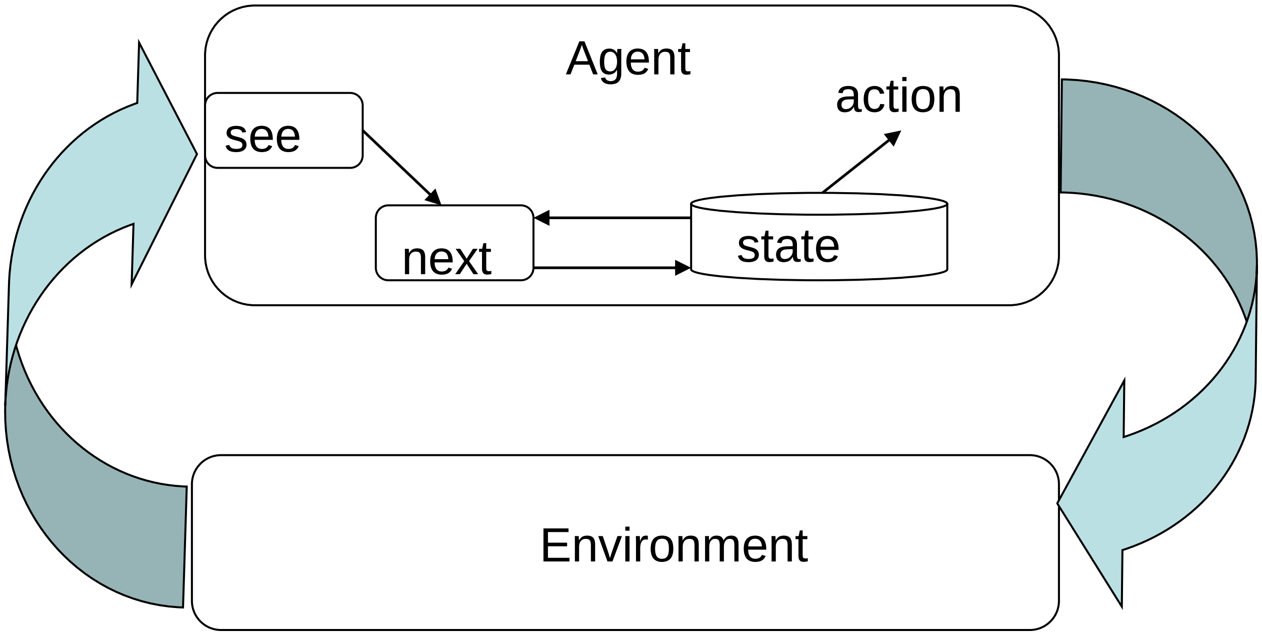


The OODA model was developed by Boyd (1987)

APPROACH—MANET AS A COGNITIVE SOCIO-TECHNOLOGY SYSTEM (CSTS): Why Agents

(a) cope with complex interaction of multiple behaviors;
(b) capable of analyzing complex adaptive information;
(c) cope with contingencies under emergence behaviors and events;
(d) recognize opportunities in a spatio-temporal manner;
(e) seek satisficing and plausible (good enough) solutions when confronted with unexpected situations with uncertain and equivocal information;
(f) represent as much as is feasible the various dimensions of expert knowledge in the domain problems

APPROACH: Agents in MANET

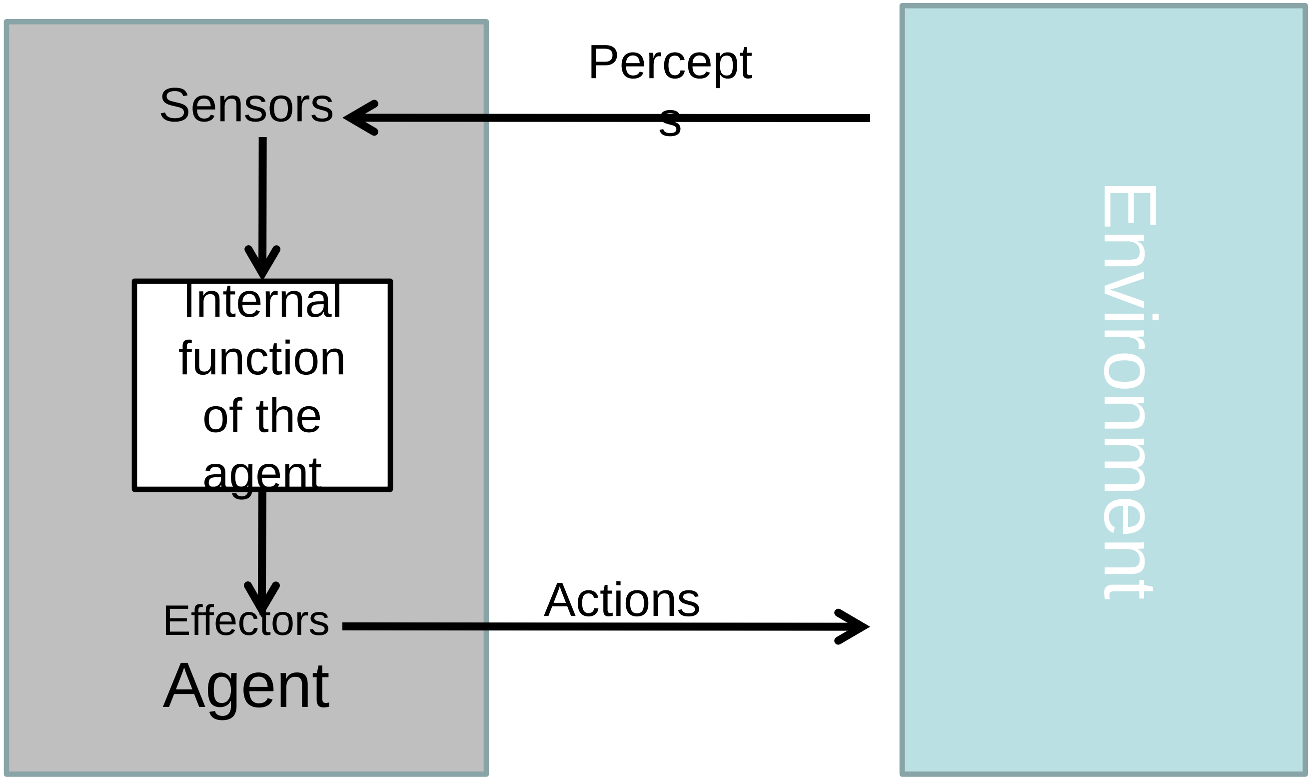


Assume the basic principle of a Rational Agent: For each possible percept sequence, a rational agent should select an action that is expected to maximize its performance measure, given the evidence provided by the percept sequence and whatever built-in knowledge the agent has.

Intelligent Agents: Theory and Practice

Michael Wooldridge Nicholas R. Jennings

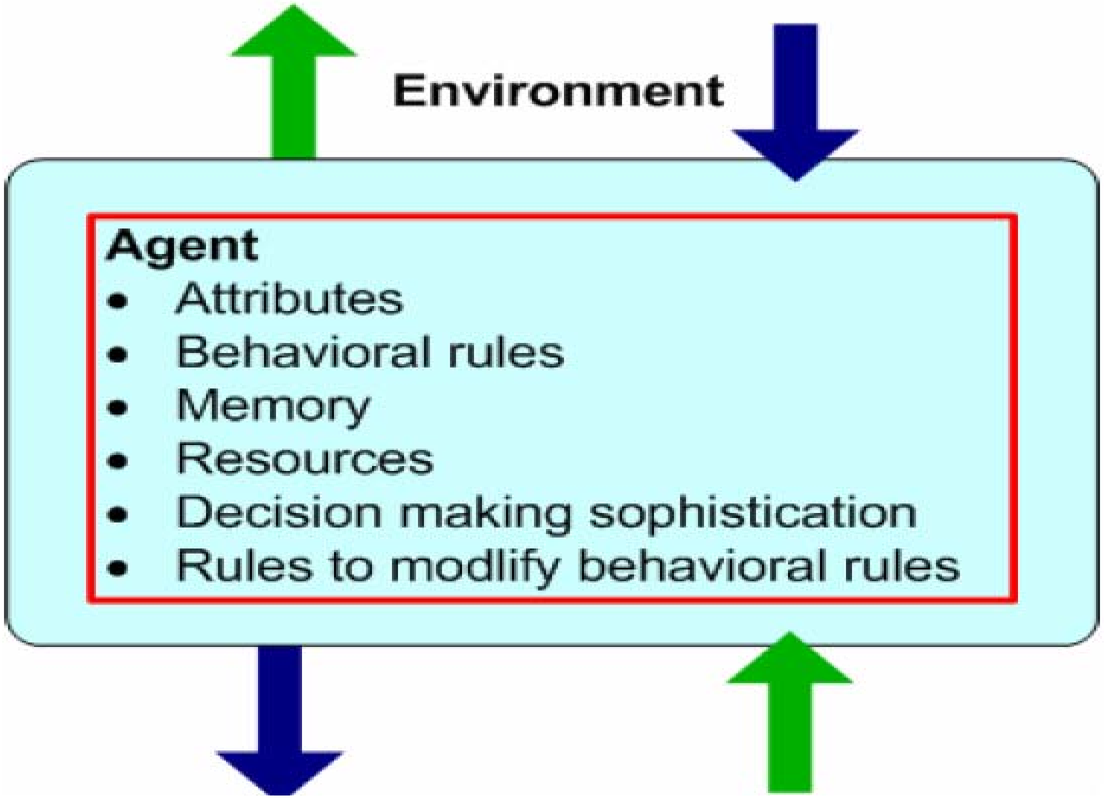
APPROACH: Agents in MANET



Russell & Norvig (2003). Artificial Intelligence: A Modern Approach; Prentice Hall.

Agents can perform actions in order to modify future percepts so as to obtain useful information (information gathering, exploration).

APPROACH: Modeling Representation

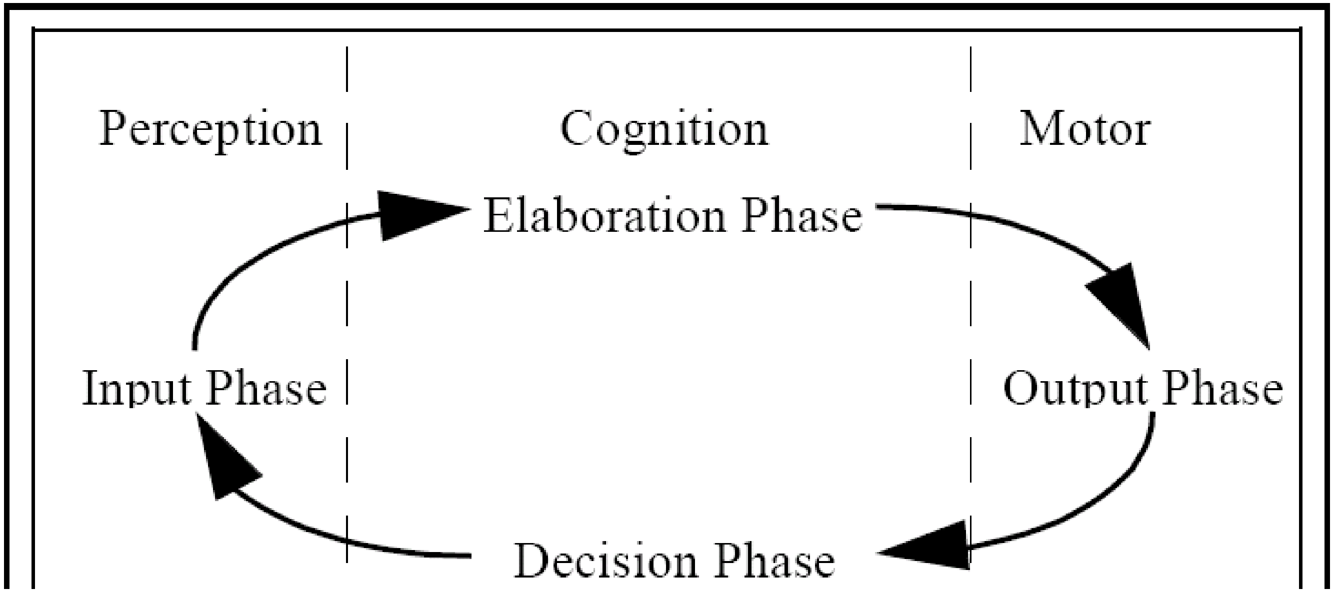


TUTORIAL ON AGENT-BASED MODELING AND SIMULATION

Charles M. Macal
Michael J. North

Each agent interacts (directly or indirectly) with one or more aspects of an environment.

APPROACH: Modeling Representation



Proc. of 8th Conference on Computer Generated Forces and Behavioral Representation, Orlando, FL, May 1999

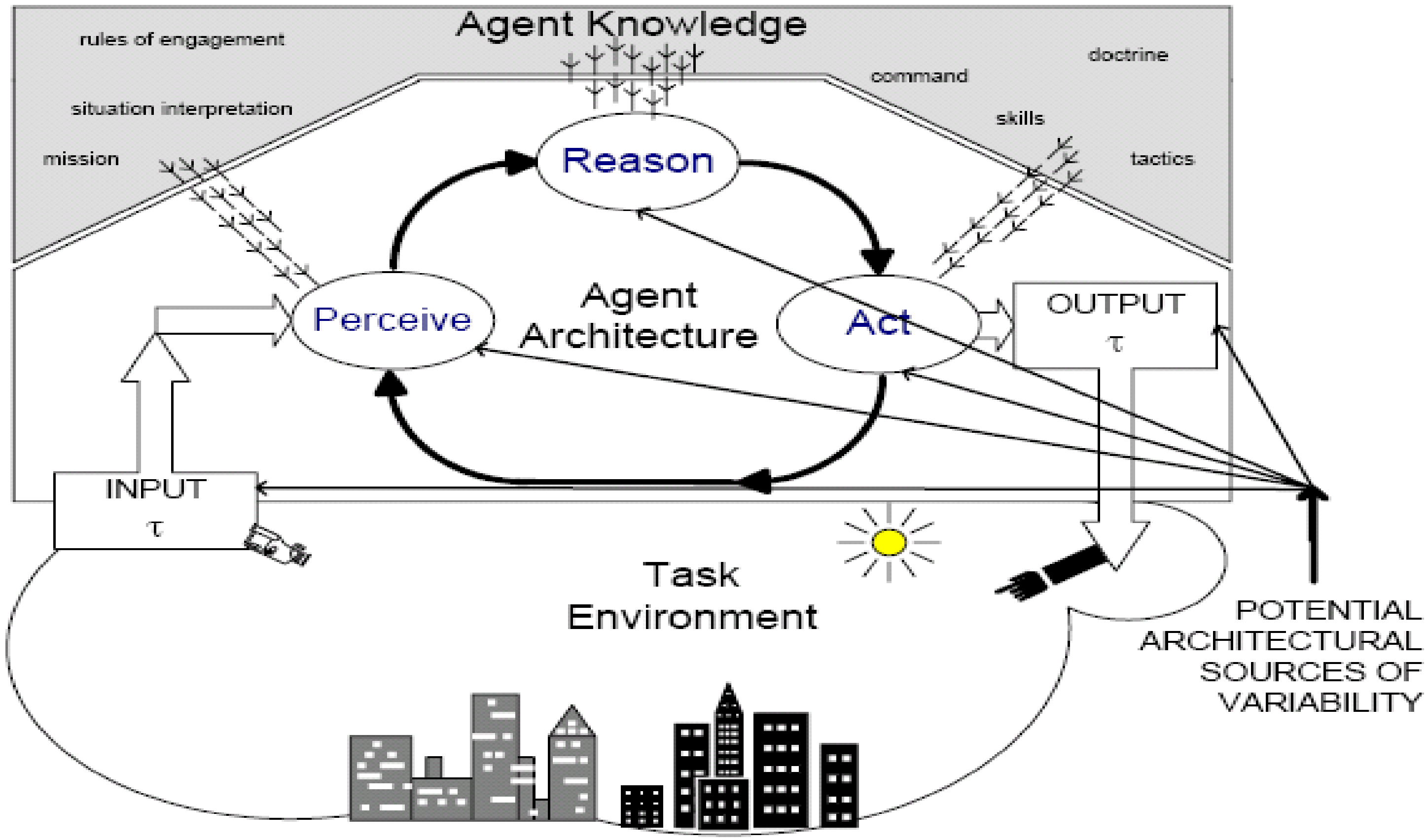
Modeling Perceptual Attention in Virtual Humans

Randall W. Hill, Jr.

<u>Agent Environments</u>
Fully vs. Partially Observable (Accessible vs. inaccessible)
Deterministic vs. Stochastic (non-deterministic)
Episodic vs. Sequential (non-episodic)
Static vs. dynamic
Discrete vs. continuous

APPROACH: Modeling Representation

Variability in human behavior most often arises from
complex interactions among the many mental and



Presented at: Behavior Representation in Modeling & Simulation Conference (BRIMS). May, 200:

Variability in Human Behavior Modeling for Military Simulations

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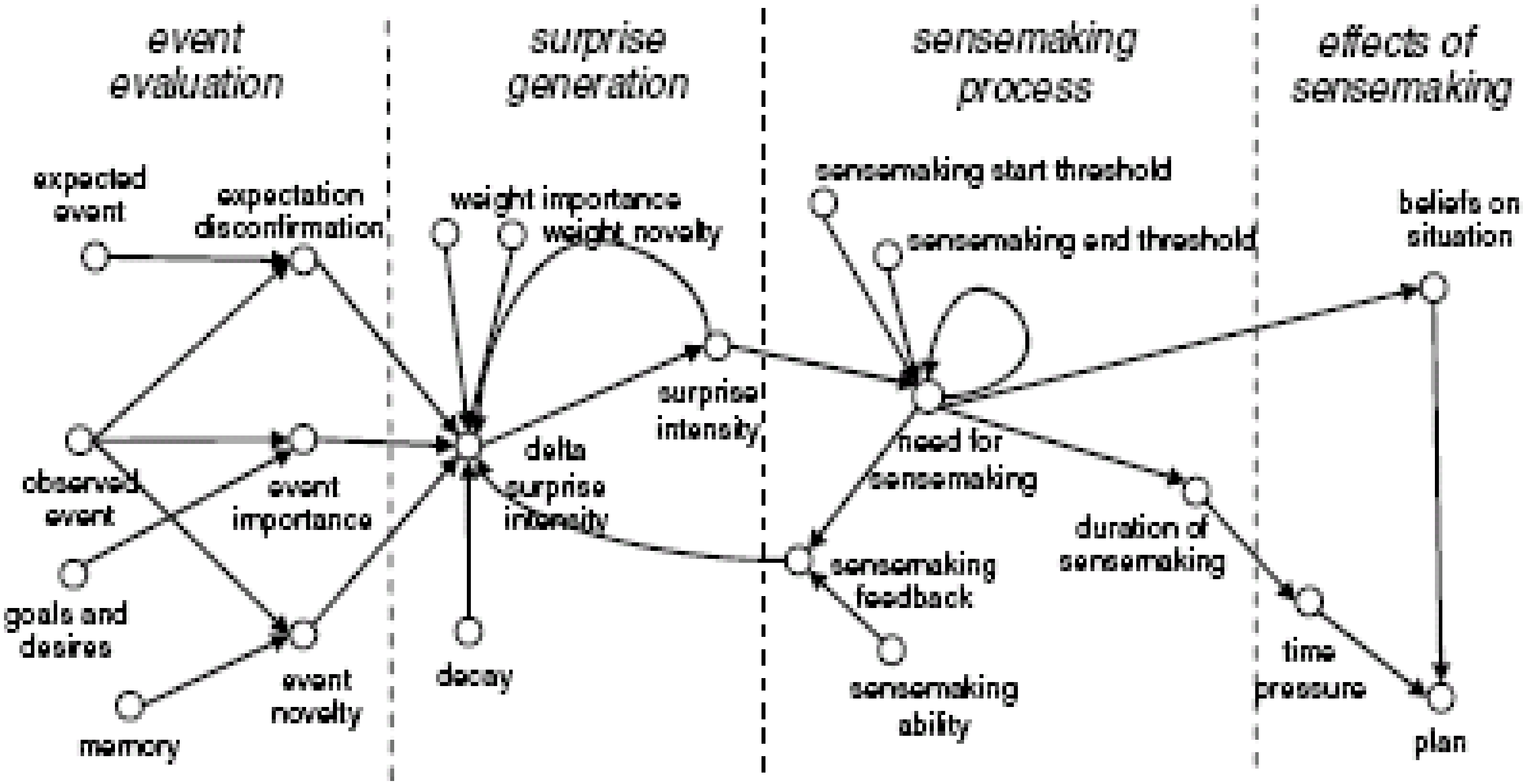
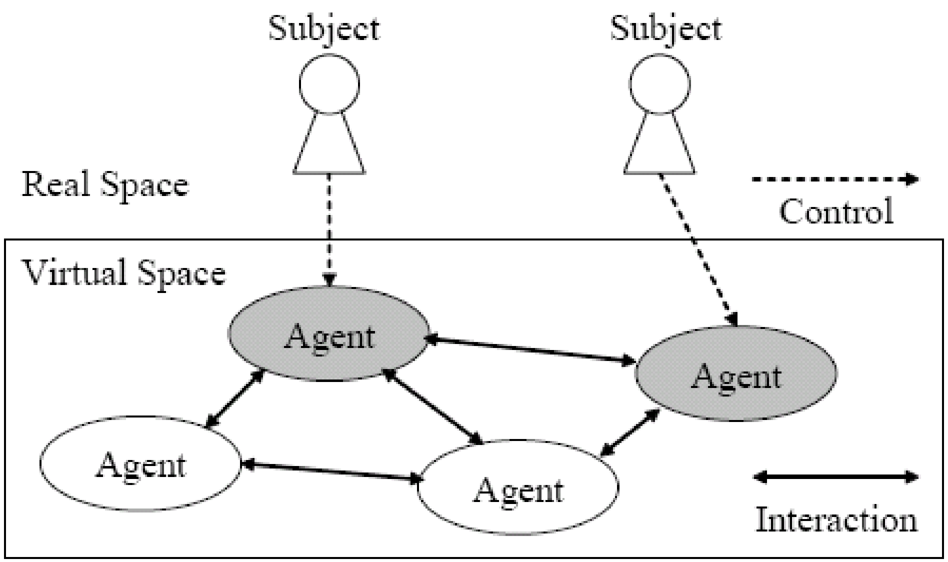
APPROACH: How We Do It



A Computational Model on Surprise and Its Effects on Agent Behaviour in Simulated Environments

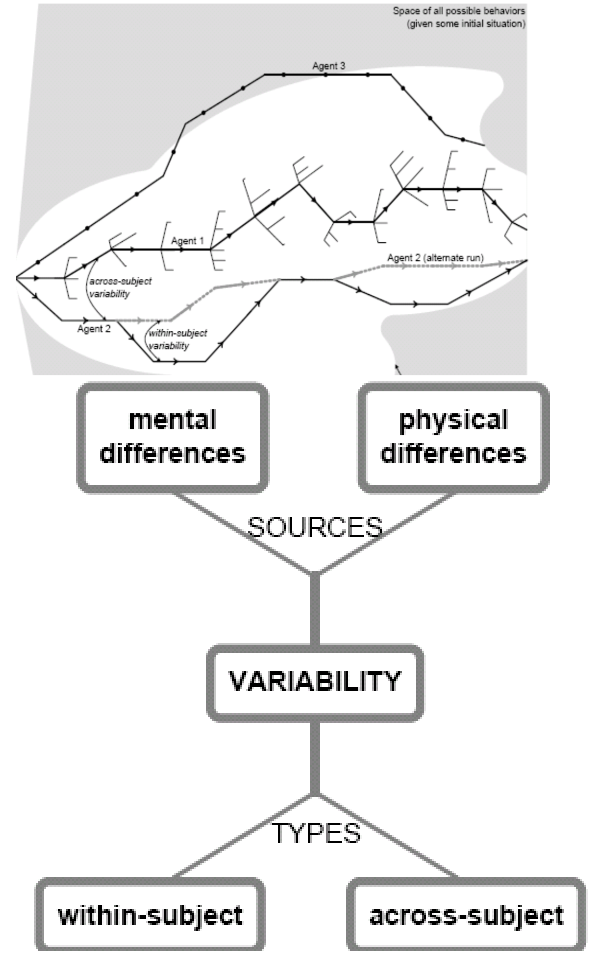
Robbert-Jan Merk

APPROACH: Considering Behavior



Modeling Human Behavior for Virtual Training Systems

Yohei Murakami and **Yuki Sugimoto** and **Toru Ishida**
Department of Social Informatics, Kyoto University



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Variability in Human Behavior Modeling for Military Simulations

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APPROACH: Modeling Behavior

information attitudes
- belief
- knowledge

pro-attitudes
- desire
- intention
- obligation
- commitment
- choice

Intelligent Agents: Theory and Practice

Michael Wooldridge   Nicholas R. Jennings

An agent is completely specified by the agent function mapping percept sequences to actions. We use a model-based reflex agent function paradigm for the prototype simulation.

PEARL SIMULATION ARCHITECTURE

Predict, **E**nvision, **A**nticipate, **R**eason, and **L**earn (PEARL)

Scenarios.

SOAP (Simulation Of Agent Perception);
SOAC (Simulation Of Agent Cognition);
SOAS (Simulation Of Agent Socio-culture); and
SOAB (Simulation Of Agent Behaviors).

KANAN: Knowledge action repository ↔

SOAP: Perception of Environment (Level 1 SA)

SOAC: Agent cognition of the problem space ↔

SOAB: Simulation model for Agent behaviors

SOAS: Social and cultural cognition ↔

An agent function can have one or all of:
Simple reflex agents: If the world is X then action Y
Model-based reflex agents: what representation describes the situation?
Goal-based agents: For situation X what should I do to achieve Y?
Utility-based agents: If I do X for situation Y, my satisfaction is Z ≥ Ω

SIMULATION (Has a Suite of 36 Major Algorithms)

SAMPLE Behavior Adaptation Algorithms

1. **Agent ID**

2. **Time :** The time agent's properties reported to the command node.

3. **Roles** : Agent's role assigned by Command Node.

4. **Physical Location (X,Y,Z)** : Agent's Current Location on the Real Map(Google Map). (Z= Zoom level)

5. **Behavior_F** : get from 'probability of failure' received from agent node (min + (max – min)*rand()) .

6. **Behavior_A** : get from 'probability of attack' received from agent node (min + (max – min)*rand()) .

7. **Behavior_AD** : Adaptability when there is enemy attack.

$$(y_{adap} = (2 / (1+e^{-kf(h,c)})) - 1$$

k = 1, f(h,c) = Trapezoidal Fuzzy Number using hostility(h) and capability(c) level

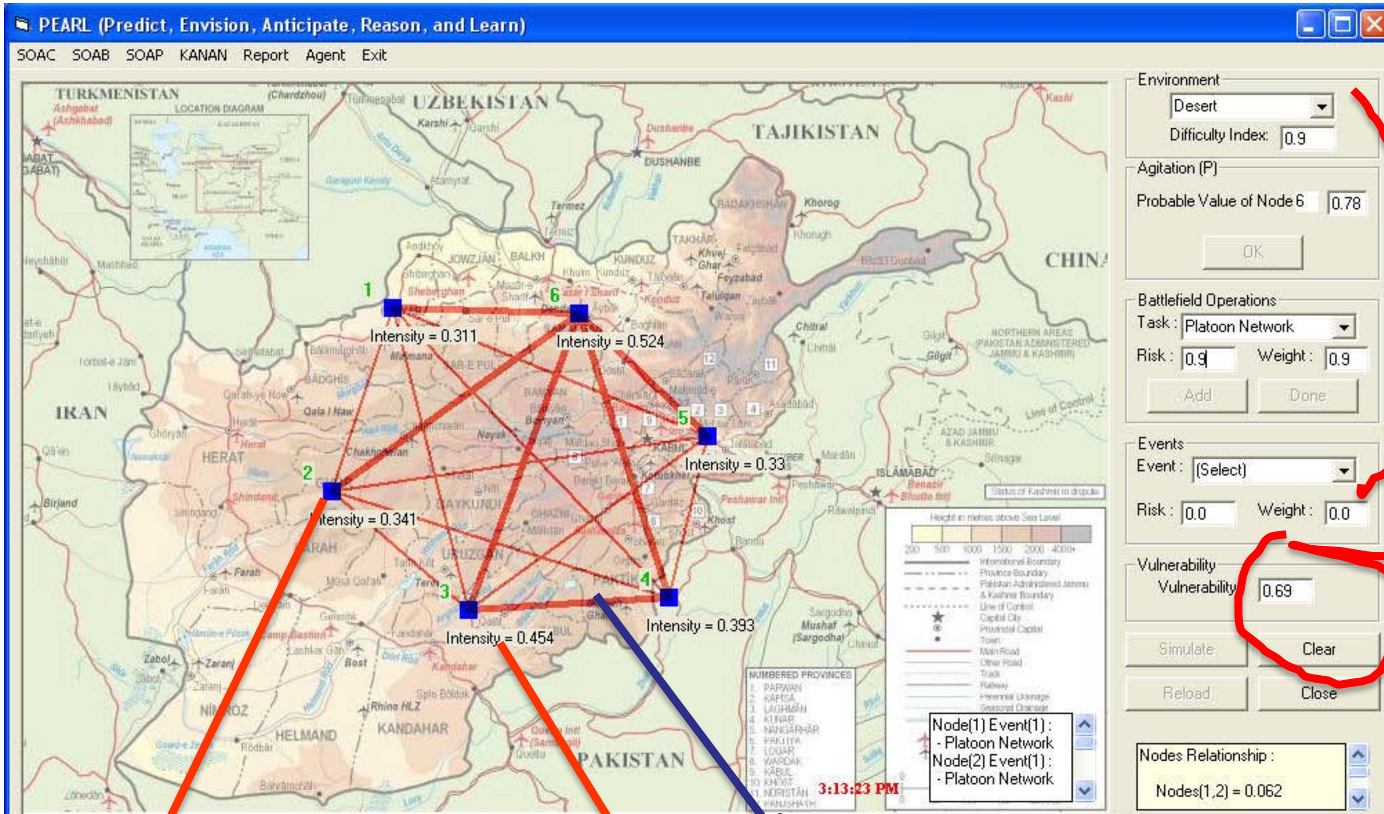
if $y_{adap} < 0$ then : Agent is Not **Adaptive**
if $0 <= y_{adap} < 0.4$ then : Agent is **Sluggishly Adaptive**
if $0.4 < y_{adap} <= 1.0$ then : Agent is **Adaptive**

8. **Perception** : get from 'Situation Awareness ability' received from agent node (min + (max – min)*rand()) .

if 0.5 < SA <= 1.0 then : **Recognize**
if 0.0 <= SA < 0.5 then : **Fail**

9. **Learning : (reinforcement learning, discounted time learning)**

SAMPLE SIMULATION RESULTS



Input parameters

Vulnerability of network during simulation = 69%

Arc size defines frequency of node- to- node interaction

Sample network topology (A MANET with 6 nodes; allowed number of nodes is arbitrary)

Sample node intensity (45.6%) calculated as aggregated parameter effects: task difficulty, interaction requirements, perception of environment, personality type, etc.

SIMULATION RESULTS

SOAC Stat.

System Status at Time = 5

Enemy Activity

	Freq.
1. Intruding	12
2. Spying	18
3. Listening to Communication	6
4. Attacking (Network)	12
5. Mimicking	12

C2 Activity

	Freq.
1. Information Flow	12
2. Network Behavior	18
3. Intruder	12
4. Discrepancy	18
5. Device Failure	6
6. Communication Failure	18

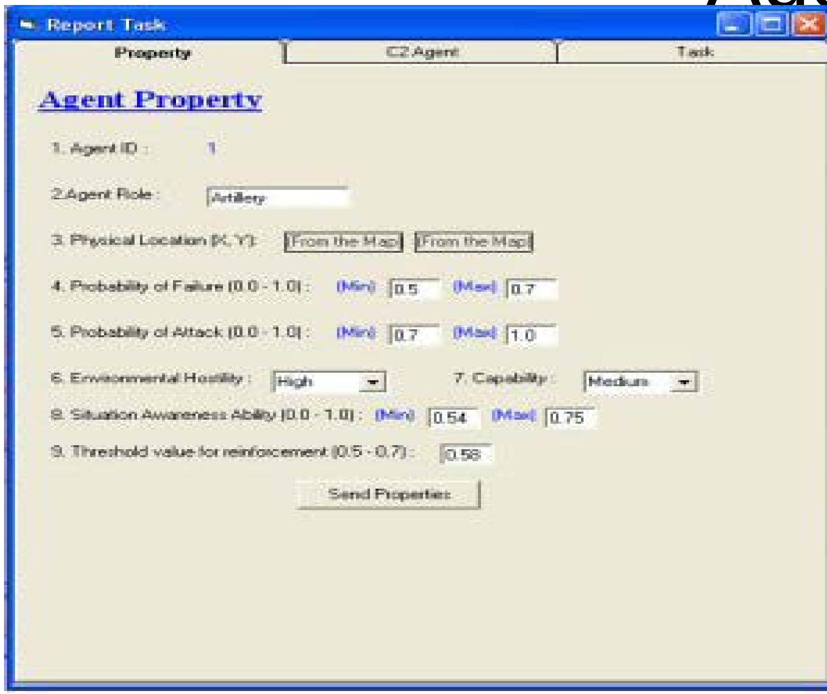
Cause (Frequency)

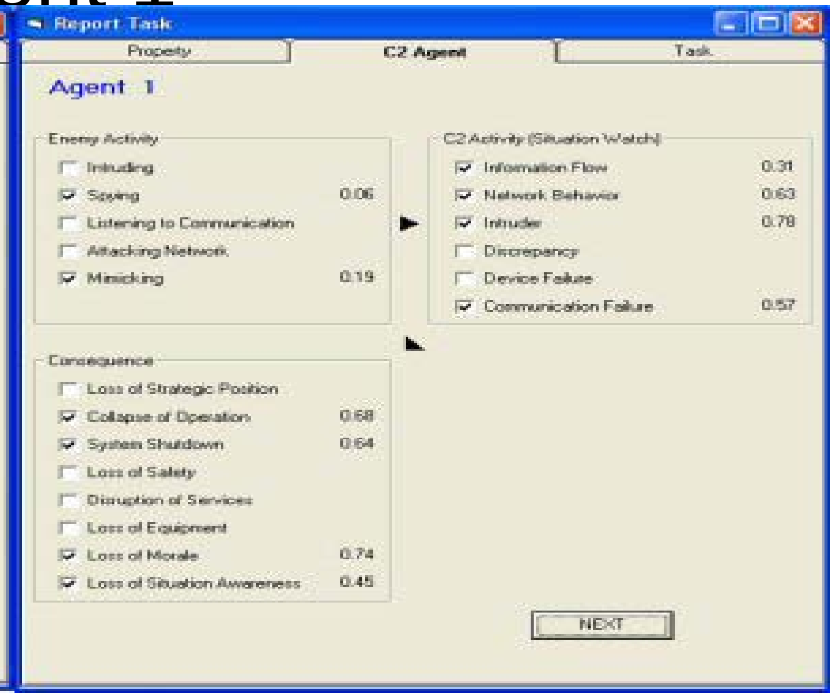
	C1	2	3	4	5	6
1. Critical Changes in Node Behavior	0	3	3	3	4	5
2. Degradation in Information	0	1	4	2	4	2
3. Loss of Information	0	1	3	2	1	3

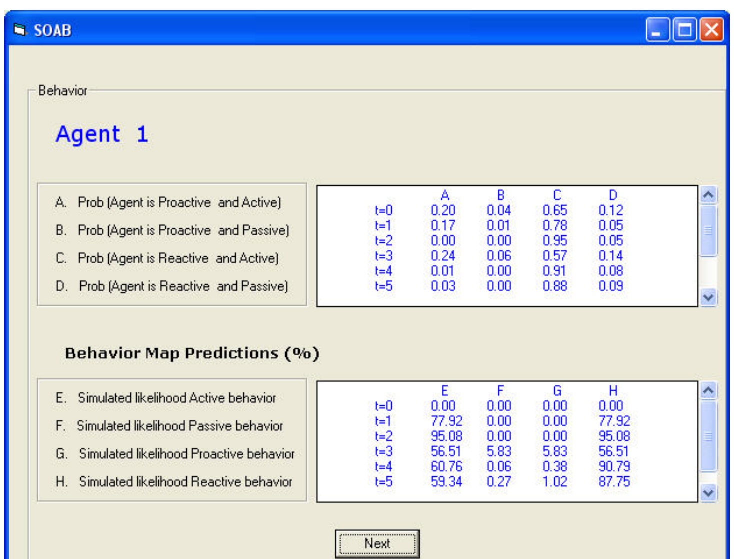
Consequence (Affected Nodes)

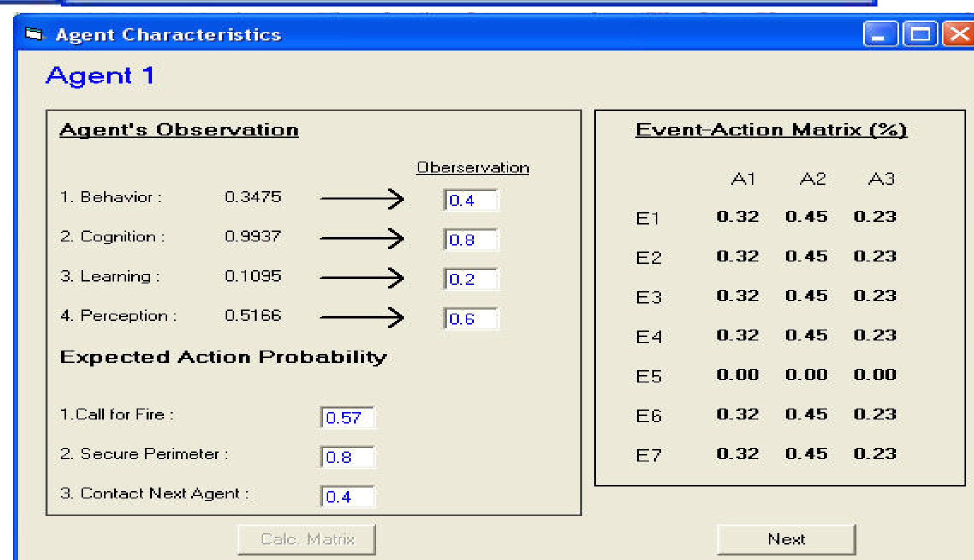
	Total Freq.	C1	2	3	4	5	6
1. Loss of Strategic Position	14	☑	☑	☑	☑	☑	☑
2. Collapse of Operaion	16	☑	☑	☑	☑	☑	☑
3. System Shutdown	11	☑	☑	☑	☐	☑	☑
4. Loss of Safety	13	☑	☑	☑	☑	☑	☑
5. Disruption of Services	19	☑	☑	☑	☑	☑	☑
6. Loss of Equipment	19	☑	☑	☑	☑	☑	☑
7. Loss of Morale	20	☑	☑	☑	☑	☑	☑
8. Loss of Situation Awareness	18	☑	☑	☑	☑	☑	☑

SIMULATION RESULTS: Sample Output – Agent 1

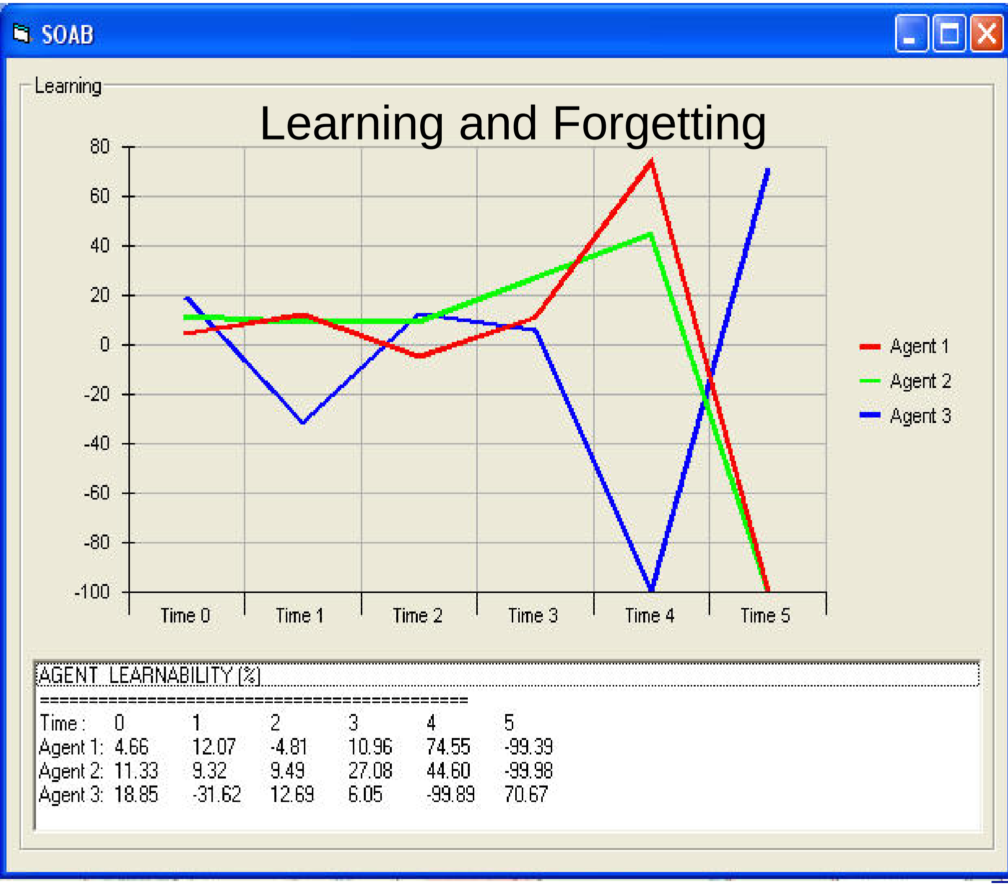


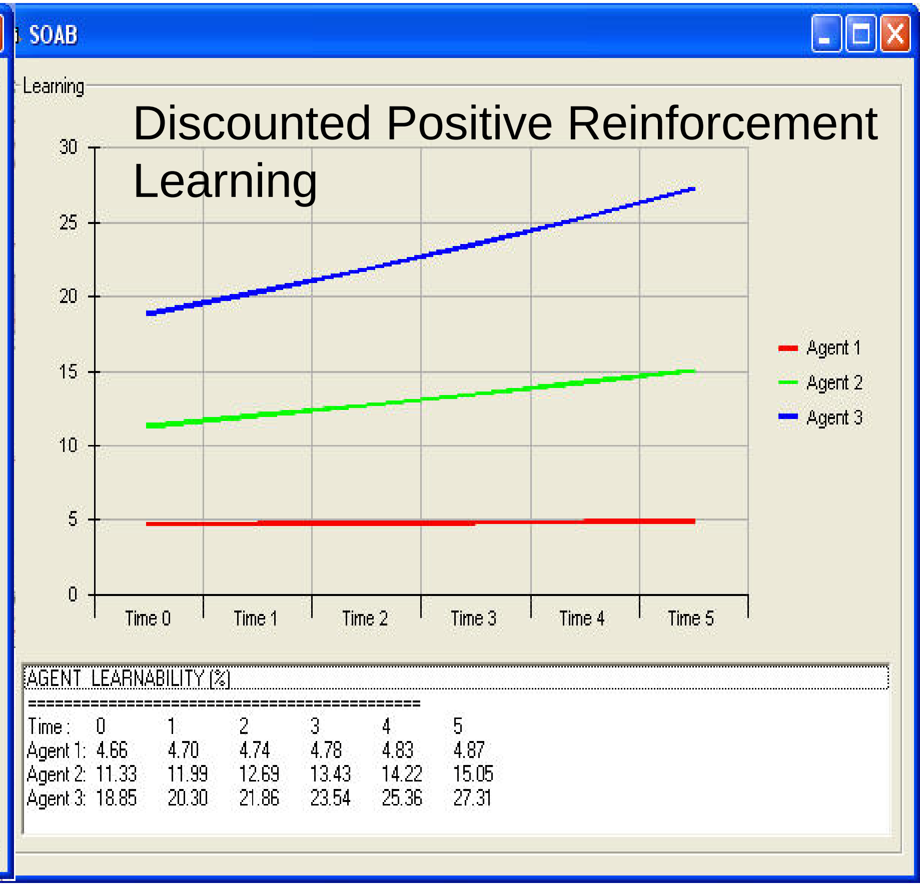






SIMULATION RESULTS: Agent Learning Profiles

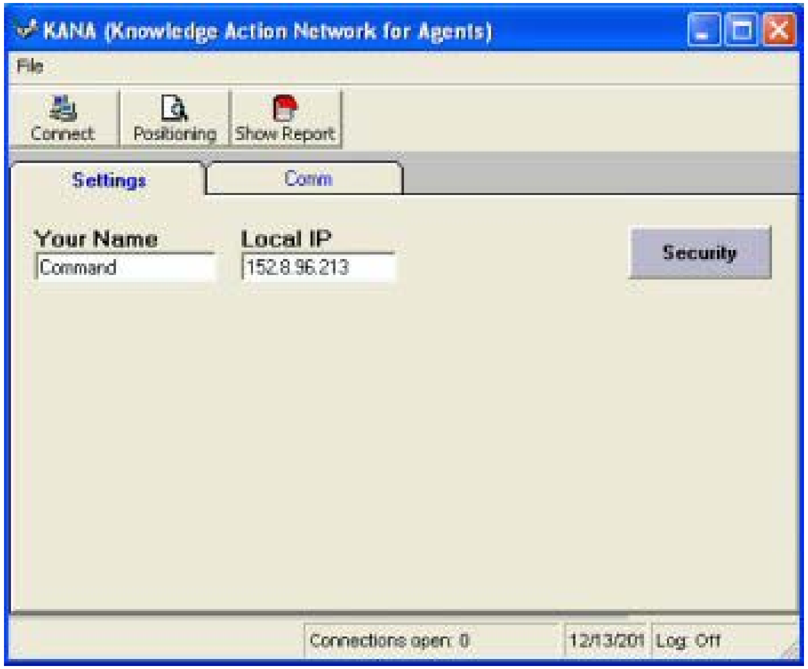




Forgetting is triggered by task conditions that disable rational and deliberate mental models –forcing the agent to ignore (or forget) routine processes.

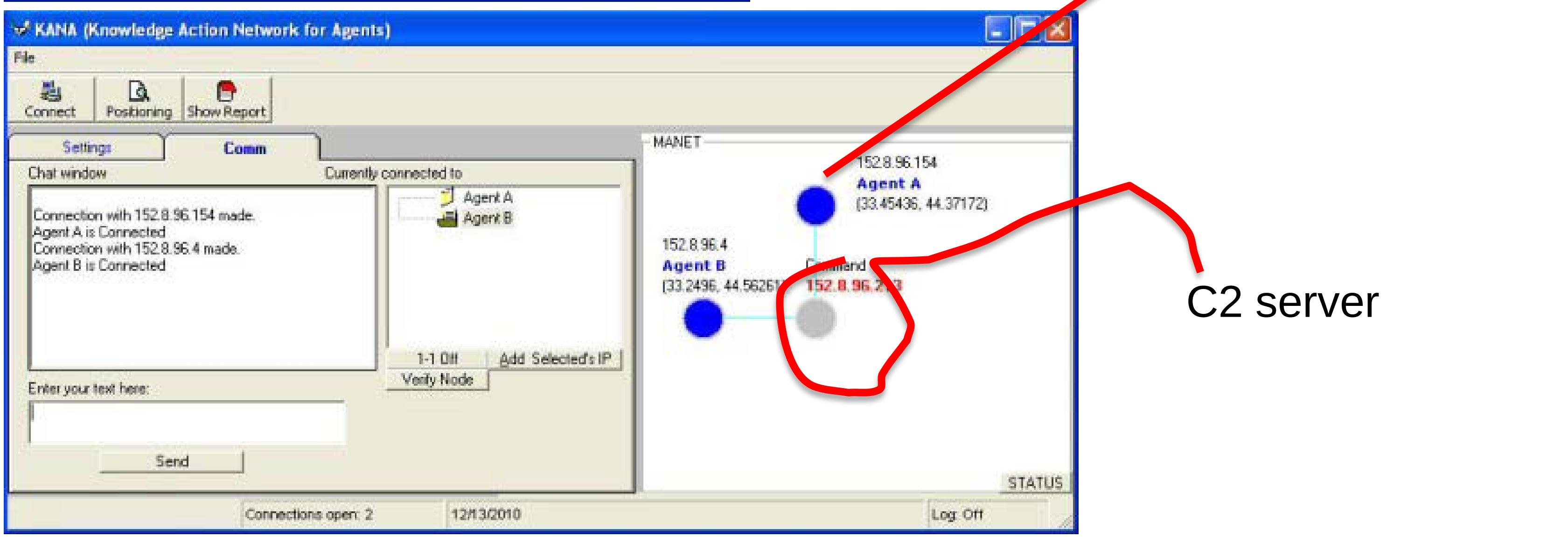
Positive reinforcement is earned by an incremental credit awarded to an agent for routinely achieving an intended goal.

APPLICATION OF SIMULATION RESULTS

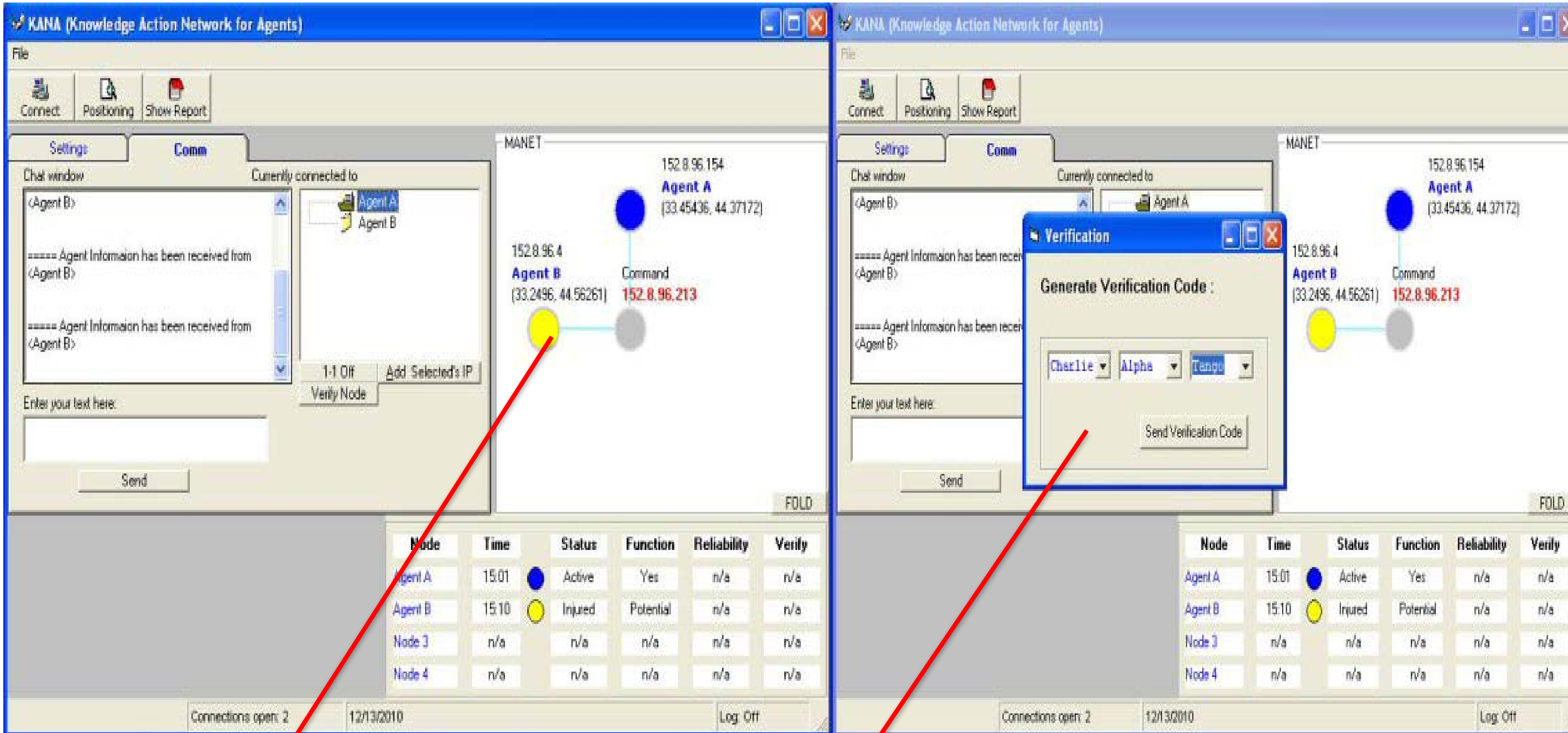


A prototype 3-node MANET with
1 C2 Server
2 field MANET agents

Log-in control by IP address.



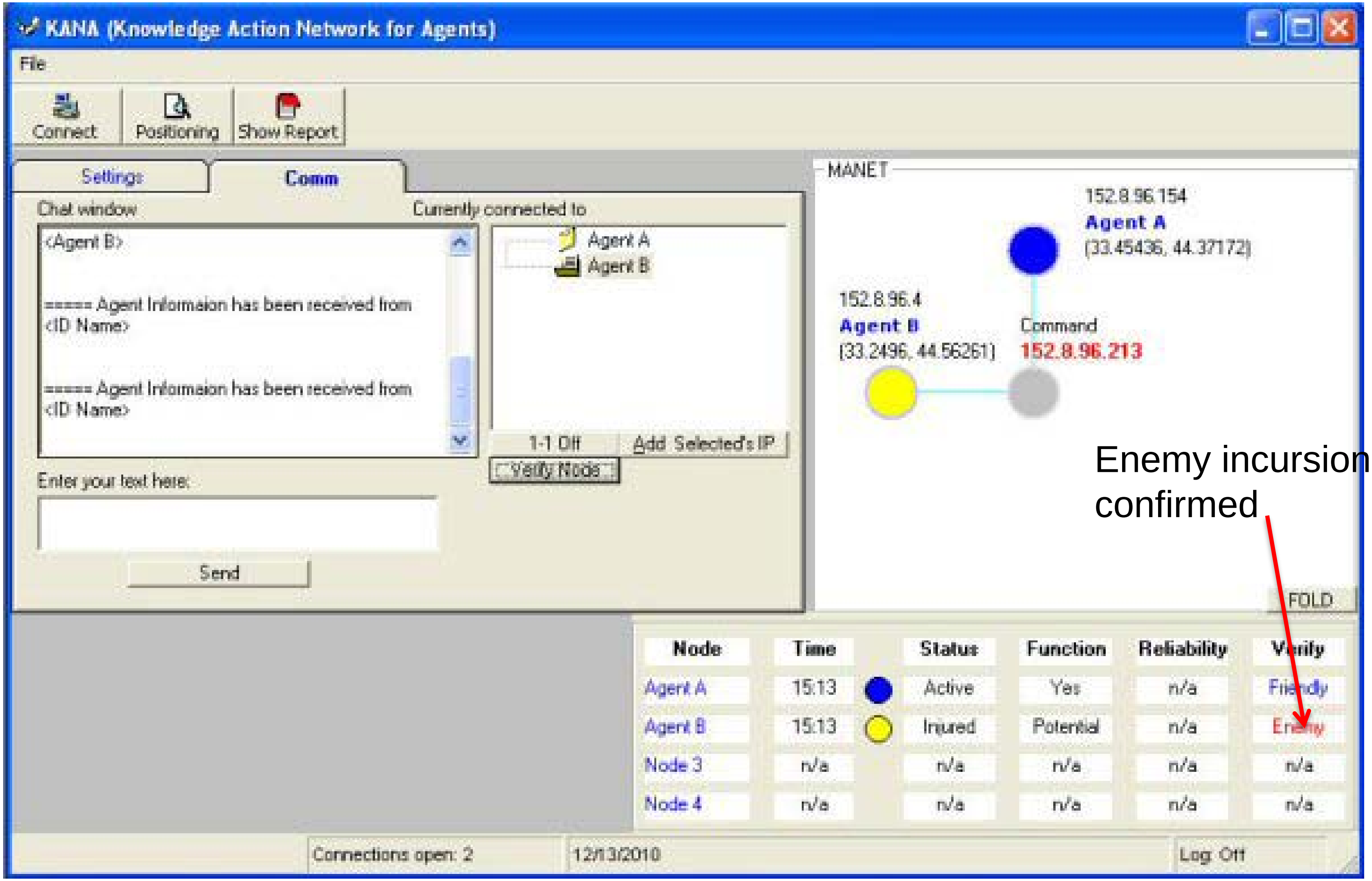
APPLICATION OF SIMULATION RESULTS



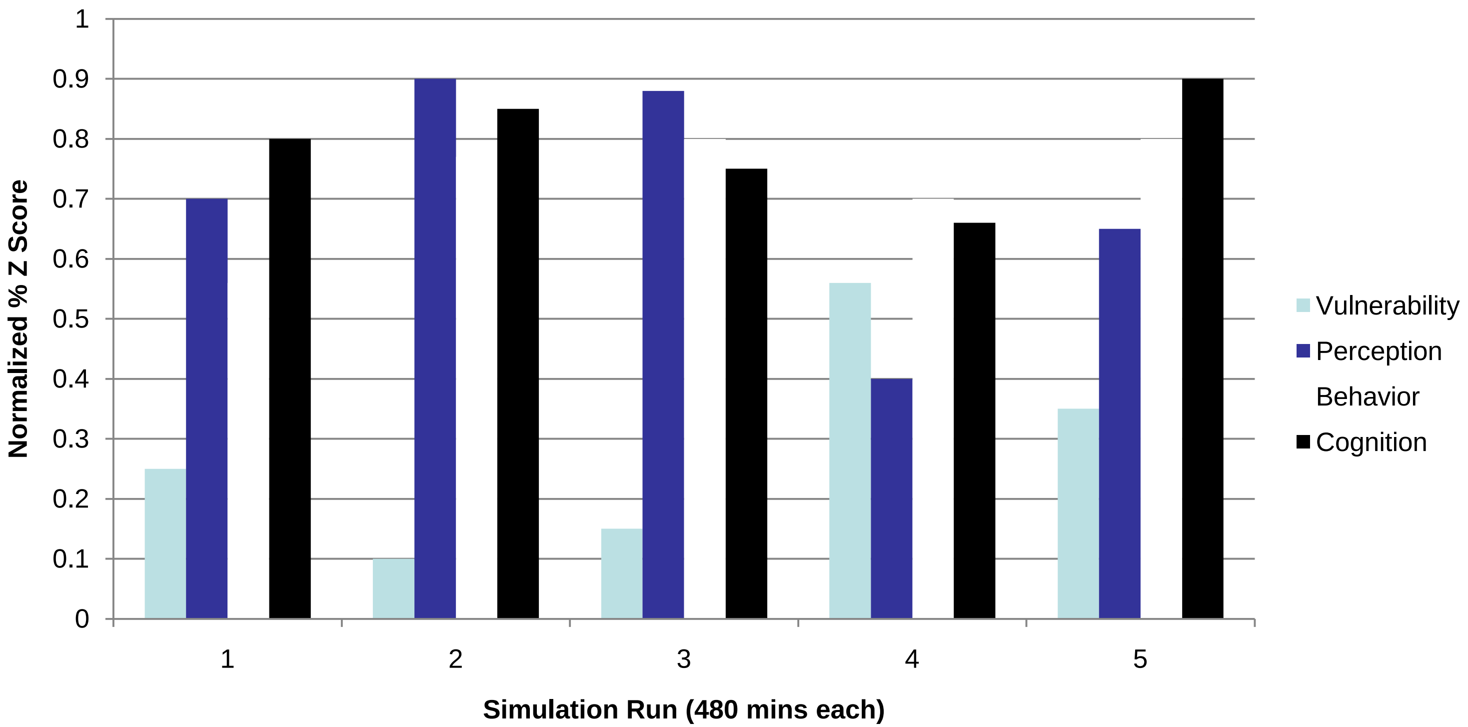
Human injury reported by agent at MANET node 2

Injury report verification by C2 server to avoid enemy mimicking node 2 behavior or status

APPLICATION OF SIMULATION RESULTS



SIMULATION RESULTS (Agent 1)



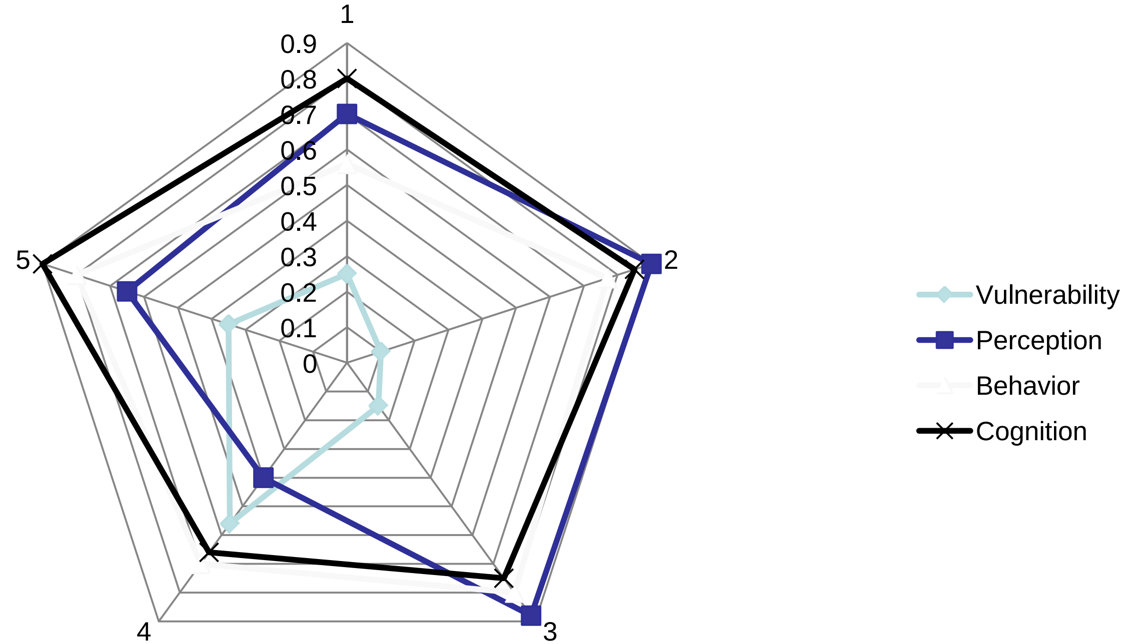
	Vul	Percep	Behavior	Cognition
Vul		-0.991	-0.198	-0.512
Percep			0.319	0.509
Behavior				0.54
Cognition				

Pearson Correlation for Simulated Period

SIMULATION RESULTS (Agent 1)

Radar Plot of Average Normalized % Scores (low = 0.0, high = 1.0)

✓Agent cognition more influential.
✓Cognition correlates positively with perception and behavior.
✓Decreased vulnerability = increased scores in cognition, behavior, and perception



Vulnerability	Perception	Behavior	Cognition
0.25	0.7	0.56	0.8
0.1	0.9	0.77	0.85
0.15	0.88	0.8	0.75
0.56	0.4	0.7	0.66
0.35	0.65	0.8	0.9

SUMMARY AND CONCLUSION

1. Modeling MANET as a cognitive socio-technical system.
2. MANET players considered collaborative agents:
3. Applied network science to capture MANET nodes as cognitive agents
4. Inject human cognitive and behavioral traits into agent-based modeling and simulation
5. Use OODA model and sensemaking paradigms to drive non-deliberate behavior of agents as rational entities (model-based functions).
6. Experiment with positive reinforcement learning (with incremental gain over time), and learning with forgetting caused by task changes).

SUMMARY AND CONCLUSION

7. Baseline Research Question: Does an agent-based MANET performance (measured by vulnerability) affected by human traits like behavior, perception, and cognitive abilities?

   (a) As agents gain and exhibit increasing perception of the problem situation, show positive rational behaviors, and gain expertise (cognition), MANET nodes are less likely to show high vulnerability during a mission.

   (b) Agents exhibit cognition, perception and behavior traits that are positively correlated.

   (c) Agents exhibit more human cognitive traits in solving problems (learning and forgetting co-exist).

SUMMARY AND CONCLUSION

8. Have demonstrated the utility of the model for use in training:
   - ✓ MANET node performance statistics.
   - ✓ Human performance as orchestrated by system interactions.
   - ✓ Levels of collaboration/ information sharing during system level mission.

9. Embellish PEARL model with other agent functional algorithms; extend to system-of systems modeling; compare performance.
10. Conduct field test to measure effects on survivability, vulnerability, lethality, and system reliability.